# Repetitive Negative Thinking in Adolescents and Young Adults – Key Features, Etiological Factors and Psychological Interventions

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Julia Sophie Funk

aus

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**Erstgutachter:** Prof. Dr. Thomas Ehring

**Zweitgutachterin:** PD Dr. Charlotte Wittekind

**Drittes Mitglied der Prüfungskommission:** PD Dr. Belinda Platt

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## Abstract

Repetitive negative thinking (RNT), such as worrying or rumination, is a well-established risk and maintaining factor for various types of psychopathology, including depression and anxiety disorders. Given that RNT is particularly prevalent among adolescents and young adults, it is a promising target for interventions aimed at reducing rising rates of mental health problems in these age groups. Furthermore, RNT-focused interventions have already proven efficacious in the treatment and prevention of different mental disorders in adolescents and young adults. Despite these promising findings, the existing literature still has some blind spots. These concern both research on the association of RNT with psychopathology and research on RNT-focused interventions.

The first part of this dissertation sought to better understand the association between RNT and psychopathology. *Study I* and *II* examined which features of the complex construct RNT best predict negative mental health outcomes. The results of *Study II* suggest that process features, e.g., the uncontrollability of negative thoughts, rather than thought content are predictive of depressive and anxiety symptoms. *Study III* demonstrated that the actual extent to which individuals engage in RNT in their daily life more consistently predicts psychopathology than retrospective estimates of the own tendency towards RNT. Taken together, these findings imply that measures of RNT should focus on process rather than content features of RNT and should assess RNT in daily life. *Study III* analyzed RNT and associated psychopathology within the context of underlying etiological factors. The study found that the genetic factors underlying worrying and somatic generalized anxiety symptoms are largely shared. Together with prior findings, this indicates that the shared genetic risk for different types of psychopathology might be mediated by RNT, but more research is needed to confirm this hypothesis.

The second part of this dissertation aimed to address research gaps concerning RNT-focused interventions for adolescents and young adults. Specifically, *Study IV* and *V* explored putative mechanisms of change and active ingredients, respectively, while also investigating the use of smartphone apps as a means of increasing the scalability of RNT-focused interventions. The results of *Study IV* indicate that change in emotional reactivity in response to stress could be a mechanism of change of RNT-focused interventions. *Study V* could not confirm its prediction that concreteness training is an active ingredient which substantially contributes to the positive effects of RNT-focused interventions; however, the null effects might have been due to methodological limitations of the study. Regarding increasing scalability, the findings of *Study*

*IV* and *V* suggest that highly scalable self-help apps are suitable for reducing stress reactivity and subclinical depressive and anxiety symptoms in adolescents and young adults – but only when frequent app usage is ensured. Additionally, differences in app design and usage patterns between *Study IV* and *V* indicate that a clear structure with designated exercises for each new intervention day is beneficial for keeping app users engaged.

In summary, this dissertation has identified specific features of the complex construct RNT that explain its association with psychopathology and has contributed evidence on how genetic and environmental risk factors influence RNT and associated psychopathology. Moreover, this dissertation has offered insights into the processes through which RNT-focused interventions might reduce psychopathology in adolescents and young adults. Finally, it has provided indications for how to increase the scalability of RNT-focused interventions for these age groups while preserving their effectiveness.

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# 1. General Introduction

*"I saw my life branching out before me like the green fig tree in the story. From the tip of every branch, like a fat purple fig, a wonderful future beckoned and winked. One fig was a husband and a happy home and children, and another fig was a famous poet and another fig was a brilliant professor, and another fig was Ee Gee, the amazing editor, and another fig was Europe and Africa and South America, and another fig was Constantin and Socrates and Attila and a pack of other lovers with queer names and offbeat professions, and another fig was an Olympic lady crew champion, and beyond and above these figs were many more figs I couldn't quite make out. I saw myself sitting in the crotch of this fig tree, starving to death, just because I couldn't make up my mind which of the figs I would choose. I wanted each and every one of them, but choosing one meant losing all the rest, and, as I sat there, unable to decide, the figs began to wrinkle and go black, and, one by one, they plopped to the ground at my feet."*

— Sylvia Plath, The Bell Jar, chap. 7 —

In her novel *The Bell Jar*, Sylvia Plath vividly portrays a young woman who struggles with depression and anxiety. The protagonist Esther Greenwood leaves her home in the suburbs of Boston, USA, after being selected for a summer internship at a prestigious magazine in New York City. Esther is a brilliant college student and seemingly an exciting summer and a bright future lie ahead of her. However, she begins to feel increasingly uncertain about her goals for the future. A spiral of "what-ifs" goes through Esthers mind again and again. Instead of helping her gain clarity, the constant overthinking leaves Esther feeling isolated and paralyzed as under a "bell jar", feeding into her anxiety and depression. Though written over 60 years ago, the novel still is widely read today. A reason for its persistent popularity could be that the protagonist's struggles with overthinking are highly relatable for many readers.

**Repetitive Negative Thinking and Psychopathology**

Esther's overthinking in *The Bell Jar* resembles a cognitive process which clinical psychologists today label repetitive negative thinking (RNT; Ehring & Watkins, 2008). The defining feature of RNT is a repetitive focus on negative contents that is experienced as intrusive and difficult to disengage from (Ehring & Watkins, 2008; Ehring et al., 2011; Watkins & Roberts, 2020). Commonly reported forms of RNT are rumination about one's own negative mood (Nolen-Hoeksema, 1991; e.g., *"why do I always feel so bad?"*), worrying about the future (Borkovec et al., 1983; e.g., *"what if I don't manage to get everything done in time?"*) and post-

event processing after social interactions (Rachman et al., 2000; e.g.,*"why didn't I behave differently?"*).

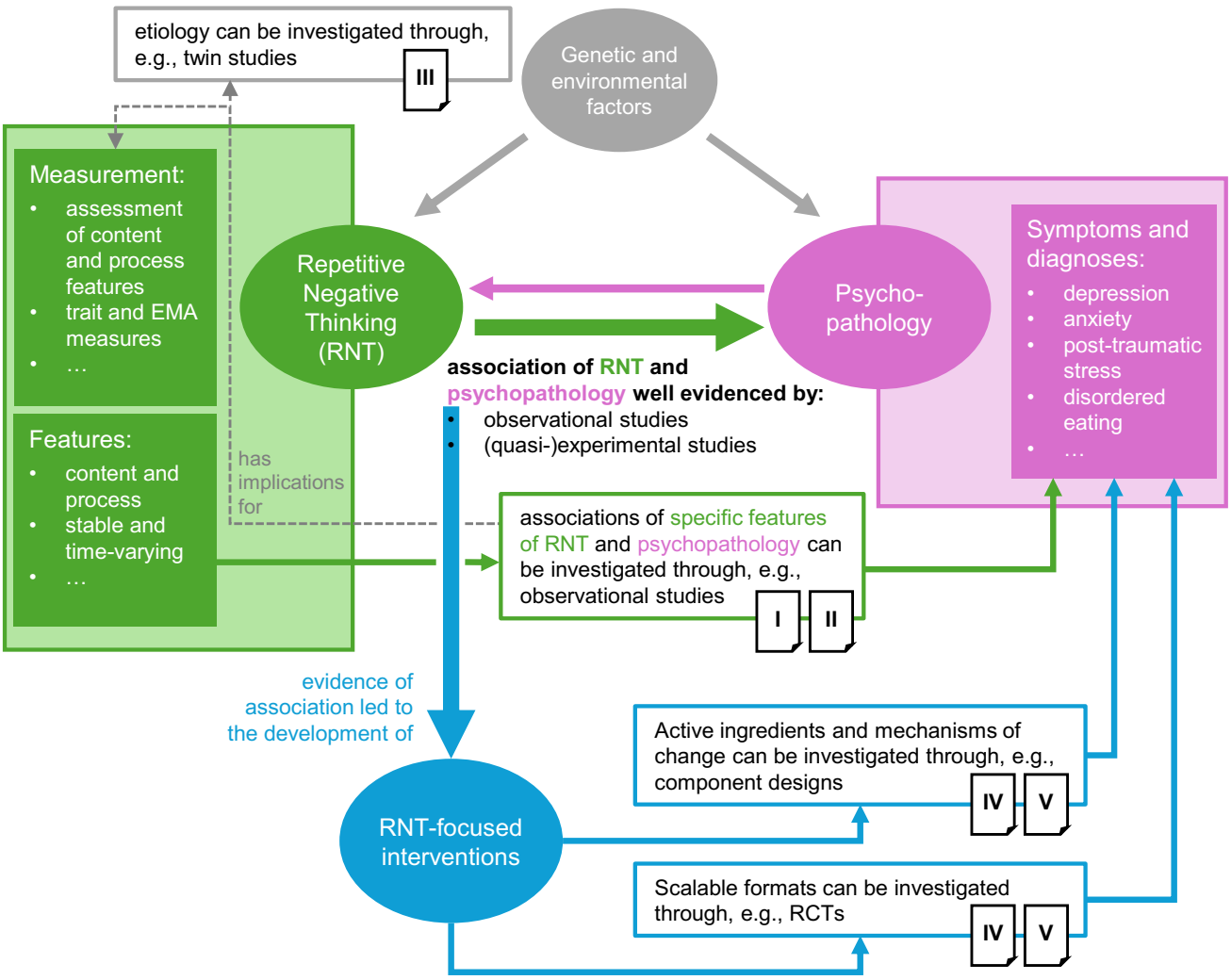
Engaging in RNT from time to time is common (Gonçalves & Byrne, 2013) and does not necessarily have negative consequences for an individuals' mental health. However, accumulating evidence suggests that excessive RNT is an important transdiagnostic process, which is involved in the development and maintenance of several mental disorders (for an overview see e.g., Ehring & Watkins, 2008; Grierson et al., 2016; Watkins & Roberts, 2020). Evidence comes from different lines of research. Firstly, quasi-experimental studies comparing groups with and without diagnoses of mental disorders showed that individuals suffering from conditions such as depression, anxiety disorders, obsessive compulsive disorder and eating disorders score higher on measures of RNT than healthy controls (e.g., Arditte Hall et al., 2019; Arditte et al., 2016; Seidel et al., 2016; Wahl et al., 2019). Secondly, cross-sectional observational studies demonstrated that the intensity of RNT correlates with the intensity of psychopathological symptoms (e.g., Samtani et al., 2021; Smith et al., 2019; Spinhoven et al., 2015). In addition, longitudinal observational studies suggest that RNT is more than just a correlate or symptom of acute mental health problems by showing that RNT predicts the development of depressive symptoms, anxiety symptoms and posttraumatic stress symptoms when controlling for baseline symptomatology (e.g., Ryum et al., 2017; Spinhoven et al., 2018; Whisman et al., 2020; Wild et al., 2016). Moreover, some longitudinal observational studies indicate that the relationship between RNT and psychopathology is bidirectional, as for instance, depressive symptoms also was found to predict later RNT (Calvete et al., 2015; Whisman et al., 2020). Finally, experimental studies in which subjects were either instructed to engage in RNT or allocated to a control condition suggest that RNT causally contributes to the development and maintenance of psychopathology (Capobianco et al., 2018; Schaich et al., 2013; Watkins et al., 2008; White & Wild, 2016). While the association between RNT and psychopathology has been demonstrated in various age groups, studies across the life span have particularly highlighted the role of RNT in adolescent and young adult psychopathology. Specifically, these studies showed that scores on RNT measures increased throughout adolescence and peaked in young adulthood (Gonçalves & Byrne, 2013; Lilly et al., 2023; Sütterlin et al., 2012).

## Research Gaps Concerning the Association Between RNT and Psychopathology

Figure 1 presents an overview of prior research on RNT and illustrates how this dissertation aims to enhance the understanding of the association between RNT and psychopathology. The main goal of most prior studies simply was to investigate whether there is a relationship between RNT and psychopathology. Their results consistently demonstrated that RNT is an important transdiagnostic process and psychological risk factor associated with several mental disorders. This well-established general association is depicted at the center of Figure 1. Although it is unquestionable that RNT is associated with psychopathology, prior research on RNT and psychopathology has some blind spots, which are indicated in white boxes with green and grey frames in Figure 1. First, RNT is a complex construct and it is not yet understood which features of RNT account for its association with poor mental health. Identifying such key features is not only of academic interest but has important implications for clinical practice, e.g., for what to focus on when assessing RNT during an intervention. Second, there is relatively little research on the etiological factors explaining why individuals differ in their tendency to engage in RNT. Investigating the relationship between RNT and different types of psychopathology within the context of underlying genetic and environmental factors could help understand shared and unique etiological pathways to different mental disorders. The following sections will describe these gaps in the literature in more detail and propose research designs that could help broaden the previously limited scope. Since RNT is particularly prevalent in adolescents and young adults, the relevance of addressing specific blind spots with regard to research on RNT and psychopathology in these age groups will be highlighted.

**Figure 1**

*Overview of prior research on RNT well as research gaps addressed by Study I to V*




*Note*. RCT = Randomized controlled trial, EMA = Ecological Momentary Assessment. Research gaps addressed by *Study I* to *V* are indicated in roman numerals.

### *Process and Content Features of RNT*

Different research gaps concern the question of which features of the complex construct RNT explain its association with psychopathology. The umbrella term RNT (Ehring & Watkins, 2008) is used to summarize different cognitive processes, for example worrying (Borkovec et al., 1983) and depressive rumination (Nolen-Hoeksema, 1991). Broadly speaking, different forms of RNT differ in thought content, e.g., rumination involves thinking about one's own sad mood (Nolen-Hoeksema, 1991) and worrying entails pondering potential future threats (Borkovec et al., 1983). Yet, different RNT forms are thought to share certain process characteristics such as repetitiveness, intrusiveness and uncontrollability of negative thoughts (Ehring & Watkins, 2008; Ehring et al., 2011). Despite these common features, worrying and rumination traditionally have been investigated separately in the context of different disorders. Worrying has been conceptualized as central in Generalized Anxiety Disorder (Borkovec & Inz, 1990), whereas rumination has been theorized to play a key role in depression (Spasojević & Alloy, 2001). However, empirical evidence shows that these associations are not that clear cut. For example, whereas worrying is a key symptom of Generalized Anxiety Disorder, it is also present in many other disorders (Ehring & Behar, 2020).

Given the similarities as well as the differences between different forms of RNT, it is of particular interest to determine which of the two are more important: specific types of thought content or process features shared across different RNT forms. Structural equation modeling provides a statistical method that can disentangle shared from unique features of different RNT forms and examine how well those predict psychopathology. Several prior studies using this method have shown that a bi-factor structure with different forms of RNT loading on a common factor, likely reflecting shared process features, as well as specific unique factors, possibly reflecting specific thought content, fits the data well (Hur et al., 2017; Samtani et al., 2021; Spinhoven et al., 2018; Taylor & Snyder, 2021; Topper et al., 2014). In addition, there is some evidence that mainly the common factor shared across different forms of RNT is predictive of later psychopathology (Spinhoven et al., 2018; Topper et al., 2014). However, well-powered longitudinal studies are scarce. Therefore, replication in large samples is warranted to confirm whether process features rather than thought content explain effects of RNT on psychopathology. Importantly, such studies could offer new insights into what to focus on when measuring RNT.

### *Stable and Dynamic Features of RNT*

In addition to questions about the role of content and process features of RNT, other research gaps relate to the fact that RNT is a dynamic process. Most people have a temporally stable tendency of how much they engage in RNT (Olatunji et al., 2023; Spinhoven et al., 2018; Struijs et al., 2020) but at the same time there is a substantial degree of fluctuation in levels of RNT over time. For example, state measures assessing present moment RNT and trait questionnaires asking respondents to provide an estimate of their general tendency to engage in RNT correlate only moderately (Marchetti et al., 2018). Furthermore, even scores on trait RNT measures show considerable fluctuation over longer periods (Olatunji et al., 2023; Spinhoven et al., 2018; Struijs et al., 2020). Critically, cognitive processes such as RNT underly stronger temporal fluctuations in adolescence and young adulthood than later in life (Thunnissen et al., 2022). These dynamic features of RNT pose different questions. It is likely that stable components of RNT generally are better predictors of psychopathology than high state levels of RNT at isolated time points. However, certain dynamic features might be important. Even when stable RNT is low, reacting with excessive RNT to certain isolated situations may be an additional factor contributing to the development and maintenance of psychopathology. For example, a person with overall low levels of RNT might become at risk for depression when engaging in RNT after the loss of their employment. Moreover, there is evidence that the severity of psychopathology is associated with the temporal stability of RNT itself; individuals with chronic mental disorders not only differ from recovered controls or those with less chronic illnesses in having higher RNT levels at single time points but also in showing less temporal variance in RNT scores (Hijne et al., 2020). Yet, the understanding of how certain time-varying features and patterns in the dynamics of RNT are related to psychopathology is currently limited by a small number of studies.

The fact that RNT fluctuates over time also has implications for questions related to the assessment of RNT. The commonly used trait measures of RNT ask respondents to estimate their general tendency towards RNT or indicate how much they engaged in RNT over a longer period of time (Ehring et al., 2011; McEvoy et al., 2010; Meyer et al., 1990; Nolen-Hoeksema & Morrow, 1991). Given the dynamic properties of RNT, this retrospective recall might lead to biased estimates that do not accurately reflect how much individuals actually engage in RNT in their daily lives. Relying merely on trait questionnaires may particularly pose a problem when aiming to assess RNT in adolescent and young adult samples as temporal fluctuations of cognitions and emotions are more pronounced in these age groups (Thunnissen et al., 2022).

Ecological Momentary Assessment (EMA) provides a method which promises more accurate measurement of RNT. Specifically, EMA enables repeated measurement of RNT in (nearly) real time (Csikszentmihalyi & Larson, 1984; Shiffman et al., 2008), e.g., via smartphone (Yim et al., 2020). Averaging RNT scores across an EMA phase might yield improved estimates of how much individuals actually engage in RNT in their daily lives. In addition, EMA offers an excellent means of recording the dynamic features of RNT and investigating their effects on psychopathology. However, despite this potential, it is not yet clear whether EMA-based RNT measures provide additional value for the prediction of psychopathology over established trait RNT measures.

### *Genetic and Environmental Factors Underlying RNT and Associated Psychopathology*

In addition to unraveling the association between different features of RNT and psychopathology, studies investigating the etiological factors that explain why some individuals develop a tendency to engage in RNT are needed to address gaps in research. When aiming to understand the environmental and genetic risks for RNT and associated psychopathology, certain complexities arise. On the one hand, RNT is considered a risk factor for psychopathology. On the other hand, certain types of RNT are seen as symptoms of mental disorders. For instance, worrying is classified as a symptom of Generalized Anxiety Disorder (American Psychiatric Association, 2013). A theoretical model that helps navigate these complexities is the model of distal and proximal risk factor for mental disorders. This model proposes that factors such as genetics and early environmental context (e.g., the experience of adversity in childhood) can be classified as distal risk factors (Nolen-Hoeksema & Watkins, 2011). These distal factors are thought to lead to mental disorders via more proximal risk factors, for example via RNT. Note that while RNT is generally conceptualized as a proximal risk factor within this framework, certain types of RNT, e.g., worrying, are better located on the level of symptoms of specific mental disorders. The most accurate reflection of RNT as a proximal risk factor might be process features of RNT, which are independent of disorder-specific thought content, i.e., a highly repetitive, intrusive and uncontrollable style of thinking about negative contents.

According to the model, distal risk factors for different mental disorders and etiological factors underlying the proximal risk factor RNT should be shared to large parts. Next to distal and proximal risk factors, the model makes assumptions about additional more specific factors, which influence the development of specific mental disorders. These factors are labeled moderators and thought to be more directly related to certain symptoms, thereby determining

whether individuals with elevated distal and proximal risk actually develop a mental disorder and which specific disorder they develop. For example, an individual with elevated distal risk due to a certain genetic makeup and associated heightened proximal risk from a tendency to engage in RNT may develop an anxiety disorder if they experience job insecurity in their early twenties. If the same person were exposed to other moderators, e.g., criticism of their weight, they might have been more prone to develop an eating disorder. Consequently, according to the model there should be specific factors (moderators) independent of RNT which raise the probability that a person with a tendency to engage in RNT develops a specific type of psychopathology.

To empirically analyze the effects of genetic and environmental factors on RNT and associated psychopathology, studies utilizing the twin design appear particularly promising. In short, this method allows to estimate the magnitude of genetic and environmental effects on the phenotype of interest by comparing how similar twins of monozygotic pairs score on a measure relative to twins of dizygotic pairs (Plomin et al., 2013). A small number of twin studies has investigated etiological factors underlying rumination. These studies yielded moderate heritability estimates (Chen & Li, 2013; Johnson et al., 2016; Johnson et al., 2014), with genetic factors explaining between 20% and 40% of the variance in rumination and the remaining variance being attributable to environmental influences. In addition, the studies analyzed the overlap between etiological factors underlying rumination and depressive symptoms (Chen & Li, 2013; Johnson et al., 2016; Johnson et al., 2014). Results showed a high overlap in genetic influences, which is in line with the model of distal and proximal risk factors and suggests that rumination might be a mediator of genetic effects on depression. In contrast, environmental factors showed more specificity to rumination and depressive symptoms, respectively. The environmental factors that were specific to depressive symptoms might reflect moderator variables as defined in the theoretical model discussed above.

When aiming to understand how mental disorders develop based on the interplay of genetic factors, environmental influences and RNT, a limitation of prior studies is that they predominantly focused on rumination. As discussed above, certain types of RNT with a particular thought content (such as rumination or worrying) might not be the most adequate reflection of RNT as a proximal risk factor for several mental disorders. Consequently, future studies on the topic should use content-independent measures focused on process features of RNT. Moreover, to account for temporal theoretical assumptions, it would be ideal to measure

the proximal risk factor RNT first and then assess symptoms or diagnoses of mental disorders with sufficient temporal distance.

Another limitation of prior research is that it has mostly focused on the etiological overlap between RNT (rumination) and depressive symptoms. This narrow focus is limiting, as RNT is a transdiagnostic factor that has demonstrated associations with multiple types of psychopathology beyond depression. Of note, one study investigated the etiological overlap between rumination and other psychopathological symptoms and found considerably less genetic overlap of rumination with eating pathology and substance dependence (Johnson et al., 2016). Therefore, to understand shared and unique etiological pathways to different mental disorders, future research on the etiology of RNT should further investigate etiological overlap with different types of psychopathological symptoms.

A third limitation of prior research on the etiology of RNT concerns the fact that the analyses did not take the dynamic nature of RNT into account. However, when aiming to understand etiological influences on psychopathology and related psychological constructs, temporal fluctuations should be considered. The reason for this is evidence that stable and dynamic components of many psychological processes and symptoms are underpinned by different etiological factors. For instance, longitudinal twin studies have shown that genetic factors largely account for stability in anxiety symptoms from time point to time point, whereas change in anxiety symptoms is rather explained by environmental influences (Nivard et al., 2015; Waszczuk et al., 2016). As such, to calculate more accurate estimates of the magnitude of genetic and environmental influences on RNT, differentiating between stable and dynamic components is crucial. This particularly applies to research in adolescents and young adults, considering that the temporal stability of RNT and psychopathology associated with RNT is lower in younger age groups (Bergen et al., 2007; Nivard et al., 2015; Petkus et al., 2016; Thunnissen et al., 2022). It is conceivable that the heritability of the temporally stable component of RNT is substantially higher than the moderate heritability of rumination at single time points found by prior studies (Chen & Li, 2013; Johnson et al., 2016; Johnson et al., 2014).

**RNT-Focused Interventions**

While not all aspects of the relationship between RNT and psychopathology are fully understood, the consistent finding that it is a crucial factor in various mental disorders, led to the development of treatments with a focus on reducing RNT, indicated in blue in Figure 1. Examples include rumination-focused cognitive-behavioral therapy (Watkins, 2016),

metacognitive therapy (Wells, 2011) and mindfulness-based interventions (Vargas-Nieto et al., 2024). Different intervention strategies aim to tackle different mechanisms that are thought to maintain RNT or to mediate effects of RNT on psychopathology. For instance, Rumination-focused cognitive-behavioral therapy (RF-CBT) builds on two key concepts. Firstly, RF-CBT conceptualizes excessive RNT as a mental habit that is rigidly triggered by various contexts and circumstances (Watkins & Nolen-Hoeksema, 2014) and aims to reduce habitual RNT by helping patients build more functional habits. Secondly, RF-CBT draws on the processing mode account of RNT (Watkins et al., 2008; Watkins, 2008) according to which negative effects of RNT are largely due to an abstract and overgeneralizing style of processing stressful experiences (e.g., "*why did this happen to me?*", "*what does this mean about me?*", "*what will happen if I always feel this way?*"). To counter this abstract processing mode, RF-CBT promotes a more concrete, solution-focused style of thinking (e.g., "*how did it happen?",* "*how do I feel now?*", "*what are concrete steps I can take to find a solution?*"). In addition, RF-CBT includes exercises focused on self-compassion and attention to present moment activities to replace abstract RNT. Mindfulness-based interventions rely on a rationale somewhat similar to the processing mode account, but lay the focus more strongly on experiential than on cognitive strategies (Segal et al., 2018). Via mediation exercises, they foster a state of fully focusing attention on the present moment without judgement as way to break abstract rumination about the past or worrying about the future. In contrast, metacognitive therapy is grounded in slightly different concepts. It is largely based on the idea that positive and negative beliefs which individuals hold about their own RNT are crucial (Wells, 2011). Accordingly, a key strategy of this treatment is to reduce RNT by identifying and addressing metacognitions such as "*I need to worry to prevent negative outcomes*" or "*if I don't manage to stop ruminating now, everything will go wrong*".

A large number of randomized controlled trials (RCTs) has provided evidence for the efficacy of RNT-focused interventions. Compared to different control conditions, e.g., waitlists or treatment as usual, RNT-focused interventions were shown to significantly reduce RNT as well as symptoms of anxiety and depression in patients suffering from depression or anxiety disorders (Bell et al., 2023; Egan et al., 2024; Goldberg et al., 2018; McEvoy, 2019; Monteregge et al., 2020; Normann et al., 2014; Watkins, 2015). In addition, targeting RNT does not only hold potential for the treatment of mental disorders but might also be effective in preventing mental disorders. For example, one RCT showed that a group intervention based on RF-CBT

significantly decreased the onset prevalences of depression and generalized anxiety disorder in participants at risk for developing these conditions (Topper et al., 2017).

## Research Gaps Concerning RNT-Focused Interventions

In summary, RNT-focused interventions have been developed based on a solid empirical basis and their efficacy has been demonstrated in several RCTs. However, to further improve RNT-focused interventions, more research is needed to understand the processes through which these interventions lead to a reduction of psychopathology (i.e., their active ingredients and mechanisms of change). Moreover, studies testing new intervention formats are crucial, as the scalability of in-person delivered RNT-focused interventions is low and the demand for interventions is high, particularly among adolescents and young adults. Research gaps concerning RNT-focused interventions are indicated in white boxes with blue frame in Figure 1. The following sections will outline these research gaps as well as ways to address them in more detail.

### *Active Ingredients and Mechanisms of Change*

Psychological interventions are complex programs consisting of several components that could theoretically be responsible for their beneficial effects on mental health. Several components are shared across many psychological interventions, such as the general healing context, the working alliance between therapist and patient and the belief in the treatment (Rosenzweig, 1936; Wampold et al., 1997). In addition, there usually are different components which are specific to a given intervention, for example engaging in self-compassion as done in RF-CBT. To identify which of the specific components of an intervention are active ingredients that significantly contribute to the effects of the intervention researchers have employed component designs. Examples include the dismantling design comparing a full intervention to an intervention without a given component that is hypothesized to be the active ingredient or additive designs testing the effects of adding a specific component to an existing treatment (Ahn & Wampold, 2001; Mulder et al., 2017). Another important concept in terms of understanding why interventions work is that of mechanisms of change (Kazdin, 2007). This concept refers to processes which mediate the effects of an intervention on its outcome. For example, a cognitive intervention could enable more positive cognitive appraisals of difficult situations (mechanism of change), which could in turn lead to reduced depressive symptoms (outcome).

Both active ingredients and mechanisms of change of RNT-focused interventions are still underinvestigated. However, one recent study has investigated putative active ingredients of an RNT-focused intervention (RF-CBT) for patients with depression by employing a full factorial component design (Watkins et al., 2023). Instead of removing, adding or isolating one of the specific components and comparing it to a package treatment as done in other component designs, participants of this trial received different (combinations of) components, allowing to investigate main effects and interactions. Results showed that absorption training promoting attention to present moment activities had a significant main effect on treatment outcomes. Yet, since this study was one of the first to investigate active ingredients of RNT-focused interventions, more research is needed to reliably identify effective components. A number of experimental studies (Guzey et al., 2021; Schaich et al., 2013; Watkins et al., 2008; White & Wild, 2016) as well as two clinical trials testing concreteness training as a stand-alone intervention (Watkins et al., 2009; Watkins et al., 2012) suggest that concreteness training is a particularly effective RNT-focused strategy. Therefore, even though the component of concreteness training did not have an effect in the study by Watkins et al. (2023), it appears promising to further investigate concreteness training as a putative active ingredient of RF-CBT.

Similar to research on active ingredients, studies on mechanisms of change of RNT-focused interventions are still scarce. A useful starting point for identifying potential mechanisms of change of RNT-focused interventions are theories or empirical research on the mechanisms that mediate the effects of RNT on psychopathology. Psychological theory (Nolen-Hoeksema, 1991) and empirical findings (Aldao et al., 2014; Blanke et al., 2021; Capobianco et al., 2018; Stefanovic et al., 2022) suggest that one mechanism by which RNT negatively impacts mental health is via intensifying emotional reactivity in response to stress. Hence, one mechanism by which RNT-focused interventions might reduce psychopathology is by attenuating this emotional reactivity. However, there is a methodological caveat to investigating this idea. Emotional reactivity in response to stress is difficult to measure by merely relying on retrospective self-report and studies using standardized stress inductions are warranted to assess this mechanism.

### *Scalability of RNT-focused Interventions*

In addition to examining the processes through which RNT-focused interventions lead to change, future studies should investigate ways to increase the scalability of RNT-focused interventions. The scalability of traditional RNT-focused interventions is low, as they have been

designed for an (one-on-one) in-person setting. Improving the scalability of RNT-focused interventions could be particularly helpful for addressing mental health problems in adolescents and young adults. First, the age of onset of mood and anxiety disorders typically lies in the teenage years or early twenties (de Lijster et al., 2017; Kessler et al., 2007; Solmi et al., 2021) and rates of mental health problems among adolescents and young adults have risen dramatically in recent years (Archer et al., 2022; Goodwin et al., 2022; Goodwin et al., 2020; Slee et al., 2021). As such, scalable interventions for treating and preventing mental disorders in these age groups are urgently needed. Second, designing scalable interventions with a focus on reducing RNT appears to be a promising strategy for promoting mental health in adolescents and young adults as excessive RNT is particularly prevalent in these age groups (Gonçalves & Byrne, 2013; Lilly et al., 2023; Sütterlin et al., 2012). Based on this rationale, three recent studies have adapted an RNT-focused intervention (RF-CBT) to be delivered in a (partly) automated web- or smartphone app-based format and tested its efficacy in adolescents and young adults at risk for developing mental disorders. Two of the studies found that the RNT-focused intervention decreased RNT as well as symptoms of depression relative to a waitlist when delivered in a guided web-based format with personalized feedback by clinicians (Cook et al., 2019; Topper et al., 2017). The third study tested whether the intervention still has similar effects when delivered in an even more scalable format by means of a self-help smartphone app without personalized feedback by clinicians (Edge et al., in press). Results showed small but significant effects of the app-based intervention on RNT, depressive and anxiety symptoms, supporting its potential as a highly scalable intervention. However, while these first results are promising, evidence for the efficacy of RNT-focused interventions when delivered in scalable web- or app-based formats is still limited by the small number of studies.

**Aims of this Dissertation**

In sum, a large body of research has shown that RNT is associated with various types of psychopathology. Moreover, RNT-focused interventions, which were developed based on these consistent findings, have proven efficacious in the treatment and prevention of different mental disorders. Given that RNT is particularly prevalent in adolescents and young adults, targeting RNT appears to be a promising strategy for interventions aimed at reducing the increasing rates of psychopathology among these age groups. However, both the prior literature concerning the association between RNT and psychopathology and prior research on RNT-focused interventions have some blind spots.

The first part of this dissertation aimed to better understand the association between RNT and psychopathology. *Study I* and *II* investigated associations between specific features of the complex construct RNT and psychopathology. *Study I* examined shared features (i.e., process features such as intrusiveness) and unique features (i.e., thought content) of different forms of RNT as predictors of depressive and anxiety symptoms. *Study II* analyzed whether average levels and dynamic features of RNT measured in daily life offer additional predictive value for psychopathology over retrospective trait RNT measures. *Study III* aimed to enhance the understanding of the association between RNT and psychopathology by exploring the underlying etiological factors. Specifically, the study analyzed to what extent worrying, a form of RNT, and somatic generalized anxiety symptoms are explained by the same genetic and environmental factors.

The second part of this dissertation aimed to provide information on the processes through which RNT-focused interventions lead to change in psychopathology. *Study IV* examined emotional reactivity in response to stress as a potential mechanism of change and *Study V* investigated concreteness training as a putative active ingredient of RNT-focused interventions. The interventions in *Study IV* and *V* were administered via smartphone through scalable self-help apps. Thus, the results of the two studies not only promise to advance intervention process research but also have implications for how to increase the scalability of RNT-focused interventions. Figure 1 indicates at which sub-fields of research on RNT and RNT-focused interventions the five studies in this dissertation are located (in roman numerals). In the following, the aims, hypotheses and design of the individual studies will be outlined in more detail.

### *Study I*

*Study I* aimed to understand the effects of shared versus unique features of different RNT forms on psychopathology. In the study, a community sample ($N$ = 523) completed a measure of worrying, a measure of rumination, two measures of process features of RNT as well as measures of depressive and anxiety symptoms at baseline and three-month follow-up. The following hypotheses were tested. It was predicted that a bi-factor model with different RNT measures loading on a common factor as well as on separate scale-specific factors would demonstrate a better fit than competing models. Moreover, it was hypothesized that the common factor of the bi-factor model would significantly predict depression and anxiety at follow-up.

### *Study II*

*Study II* investigated whether an EMA measure assessing RNT in daily life predicts symptoms of depression and anxiety as well as well-being when controlling for established trait RNT measures in a sample of adolescents and young adults ($N$ = 1,176). The study comprised a baseline and three follow-up assessments over the course of one year, in which trait RNT, depressive symptoms, anxiety symptoms and well-being measures were administered. The 10-day EMA phase took place shortly after baseline and included a recently developed EMA protocol that assesses process features of RNT in participants' everyday lives (Rosenkranz et al., 2020). As a primary index of RNT in daily life, the average RNT score across all completed EMA measurement time points was computed. It was hypothesized that higher average scores on the EMA measure would predict higher depressive and anxiety symptoms as well as lower well-being when controlling for established trait RNT measures. In addition, the effects of certain patterns in RNT dynamics on psychopathology were explored, for example, by analyzing whether RNT inertia (the resistance of RNT to change) predicts psychopathological symptoms.

### *Study III*

Generalized anxiety is defined by worrying, a form of RNT, as well as by somatic anxiety symptoms, such as constantly feeling tense and nervous (American Psychiatric Association, 2013). *Study III* aimed to explore whether worrying and somatic generalized anxiety symptoms represent two statistically distinct dimensions and to examine overlap and specificity in etiological factors underlying these dimensions in a young adults' twin sample ($N$ = 10,836). In addition, the study aimed to quantify genetic and environmental contributions to stable generalized anxiety as well as to possible stable symptom dimensions across young adulthood. Due to limited prior evidence, no predictions were made in terms of dimensions and underlying etiological factors. Regarding etiological influences underpinning stable generalized anxiety, it was hypothesized that the heritability estimate of stable generalized anxiety would be higher than the heritability estimates at any single time point. To answer its research questions, *Study III* used data from a large ongoing longitudinal twin cohort, the Twins Early Development Study (TEDS; Lockhart et al., 2023). The study was conducted based on the most recent six waves of TEDS, with mean age of the twins 23 years at the first and 26 years at the last of these six waves.

***Study IV***

*Study IV* investigated whether change in emotional reactivity in response to stress could be a mechanism of change of RNT-focused interventions. Specifically, the study tested the effects of an intervention based on RF-CBT on stress responses in a highly controlled laboratory setting. Young adults with high levels of RNT ($N = 79$) either received the 10-day RNT-focused intervention via smartphone app or were allocated to a control condition before being confronted with a standardized laboratory stressor (Trier Social Stress Test; Kirschbaum et al., 1993). During the intervention, participants had to complete short exercises (10-15 min/day) designed to address habitual RNT and train helpful processing modes incompatible with RNT (e.g., concrete thinking and self-compassion) in the app. Self-report measures of negative affect, RNT and stress appraisals as well as measures for biological stress responses (salivary cortisol and alpha amylase) were administered at several time points before and after the stressor. Using this data, it was analyzed whether participants in the intervention condition would show reduced subjective and biological stress responses relative to participants in the control condition.

***Study V***

*Study V* aimed to investigate concreteness training as a putative active ingredient of RF-CBT, while at the same time testing whether self-help apps are suitable formats to deliver RNT-focused interventions. The study was set up to be a prevention trial in a sample at risk for developing mental disorders. Adolescents and young adults with high levels of RNT but no current depression or anxiety disorder at baseline ($N = 365$) were randomly allocated either to a waitlist or to receive one of two RNT-focused interventions: the full RNT-focused intervention or the concreteness training only intervention. The full RNT-focused intervention comprised the same contents as the intervention in *Study IV* but was administered in a less structured way and over a longer period. Participants could freely choose from a range of exercises in the app over the course of six weeks instead of following a structured plan with designated exercises for each day. The concreteness training only intervention app employed the same design and basic structure as the full RNT-focused intervention app but focused exclusively on training concrete thinking. The following hypotheses were tested. It was predicted that both app-based interventions would decrease depressive symptoms, anxiety symptoms and RNT relative to the waitlist.

# 2. Study I:

*The Bi-Factor Model of Repetitive Negative Thinking: Common vs. Unique Factors as Predictors of Depression and Anxiety*

This chapter is a post-peer-review, pre-copyedit version of an article published in the *Journal of Behavior Therapy and Experimental Psychiatry.*

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## Abstract

**Background and Objectives:** Different forms of repetitive negative thinking (RNT) have traditionally been conceptualized as being distinctly linked to specific disorders. However, emerging evidence suggests that a common process lies at the core of different RNT manifestations. This common process might also largely explain the link between RNT and psychopathology. To examine the latent factor structure of RNT, we compared three structural-equation models, assuming (a) a common factor across different RNT measures (single-factor model); (b) scale-specific factors for each RNT measures (separate-factor model); and (c) both a common and scale-specific factors (bi-factor model). We additionally tested whether these latent factors predicted depression and anxiety at a follow-up time-point.

**Methods:** A community sample ($N$ = 523) completed an online assessment comprising measures of rumination, worry and content-independent RNT as well as depressive and anxiety symptoms at baseline (t1) and three months later (t2).

**Results:** The bi-factor model showed the best fit to the data among the three models. Moreover, the common factor of the bi-factor model significantly predicted depression and anxiety three months later. Next to the common factor, some but not all scale-specific factors additionally predicted symptoms.

**Limitations:** The study was conducted in a non-clinical sample and the assessment of psychopathology was restricted to depressive and anxiety symptoms.

**Conclusions:** The findings support transdiagnostic conceptualizations of RNT, which highlight common aspects of different forms of RNT as well as the relevance of RNT across different diagnostic categories.


**Keywords**: repetitive negative thinking, rumination, worry, transdiagnostic processes, depression, anxiety

# Introduction

Substantial evidence suggests that repetitive negative thinking (RNT) is a risk factor for mental health problems (Ehring & Watkins, 2008; Watkins, 2008; Watkins & Roberts, 2020). The overarching construct of RNT can be defined as repetitive thinking about one or more negative topic(s) that is experienced as difficult to control (Ehring & Watkins, 2008; Ehring et al., 2011; Kaplan et al., 2018; Segerstrom, Stanton, Alden, & Shortridge, 2003; Wahl et al., 2019). Further features of RNT are that it captures mental capacity, is perceived as unproductive (Ehring & Watkins, 2008) and is characterized by an abstract, overgeneralizing processing style (Watkins, 2008).

One important phenomenon typically subsumed under the umbrella concept of RNT is rumination, which in the context of depression is defined as reacting to low mood by repetitively thinking about the causes, meaning and consequences of feeling sad (Nolen-Hoeksema, 1991). Rumination has repeatedly been found to intensify symptoms in patients with depression (Just & Alloy, 1997; Nolen-Hoeksema, Morrow, & Fredrickson, 1993; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Furthermore, rumination has been shown to increase the risk for future depression in currently healthy individuals (Just & Alloy, 1997; Nolen-Hoeksema, 2000; Whisman, du Pont, & Butterworth, 2020). Another form of RNT is worry, which is defined as repetitively thinking about potential future problems (Borkovec, Robinson, Pruzinsky, & DePree, 1983). Worry is a key symptom of generalized anxiety disorder (American Psychiatric Association, 2013) but also present in many other disorders (Ehring & Behar, 2020). While rumination and worry can both be conceptualized as forms of RNT, they differ in thought content and temporal orientation (Beck, Brown, Steer, Eidelson, & Riskind, 1987; Beck & Perkins, 2001; Goring & Papageorgiou, 2008). Specifically, rumination is characterized by thoughts about the self and negative past events, whereas worry typically involves thoughts about uncertain outcomes or threats of future events. Moreover, worry and rumination have been studied in the context of different mental disorders in the past, with rumination being regarded as a key process in depression (Spasojević & Alloy, 2001) and worry as a central element of generalized anxiety disorder (Borkovec & Inz, 1990).

## RNT as a transdiagnostic process

There is an ongoing debate on whether different forms of RNT essentially share a common process or whether they can better be understood as correlated but distinct factors. This is not just of academic interest, but also has potential clinical relevance as it determines

whether treatments should target RNT as a transdiagnostic process (commonly found across different mental disorders) or should focus on different manifestations of RNT as distinct phenomena within specific disorders. The question of how to conceptualize and address RNT is part of broader debate on the structure of psychopathology. Recent transdiagnostic approaches have challenged traditional classificatory nosology (Caspi et al., 2014; Insel et al., 2010; Kotov et al., 2017). Bi-factor approaches, for instance, propose that different mental disorders share a single latent dimension, sometimes referred to as general psychopathology or p factor (Caspi et al., 2014) which is proposed to explain high rates of concurrent and sequential comorbidity among mental disorders. Next to a p factor, bi-factor concepts of psychopathology identify more specific factors that are uniquely related to some types of psychopathology (Caspi et al., 2014; Hankin et al., 2016). A recent commentary on using bi-factor analyses in psychopathology research concluded that bi-factor concepts can improve our understanding of psychological phenomena when there are indications for the presence of a common as well as more specific factors (Bornovalova, Choate, Fatimah, Petersen, & Wiernik, 2020). With regard to RNT, on the one hand, there is evidence supporting the notion of a common underlying process, for example, worry and rumination are highly correlated (de Jong-Meyer, Beck, & Riede, 2009; Eisma, de Lang, & Boelen, 2020; Gustavson, du Pont, Whisman, & Miyake, 2018). On the other hand, exploratory factor analyses have sometimes revealed distinct factors underlying worry and rumination, respectively (e.g., Fresco, Frankel, Mennin, Turk, & Heimberg, 2002; Hong, 2007), suggesting that specific factors might also be important.

**The Latent Factor Structure of RNT**

Concepts such as bi-factor models can be tested formally by using structural equation modeling (SEM). Researchers have recently begun to apply SEM to existing questionnaire measures of rumination, worry and repetitive thinking in order to investigate the latent factor structure of RNT. The main focus in this line of research is on comparing different latent factor models representing competing conceptual theories of RNT. The traditional concept of worry and rumination as separate constructs can be expressed by a separate-factor model. This model assumes that the items of the different questionnaires exclusively load on a respective scale-specific factor (see Figure 1.a). In contrast, a single-factor model, in line with a radical transdiagnostic concept of RNT (McEvoy, Mahoney, & Moulds, 2010), proposes that the items of all questionnaires exclusively load on one common factor (see Figure 1.b). Combining these two perspectives, a bi-factor model reflects the increasingly prevailing view that different types of RNT share a common process but differ in some regards, i.e., in content and temporal

orientation. The logic of a bi-factor model is depicted in Figure 1.c. Specifically, the bi-factor model of RNT assumes that each item of each scale is loading on a common as well as on a respective unique, scale-specific factor.

A growing body of SEM analyses indeed suggests that a bi-factor model may be well suited to represent the way, in which different forms of RNT are related. The bi-factor model of RNT consistently demonstrated good model fit (Samtani et al., 2021; Spinhoven, Drost, van Hemert, & Penninx, 2015; Taylor & Snyder, 2021), and outperformed alternative models such as separate- and single-factor models (Hur, Heller, Kern, & Berenbaum, 2017; Spinhoven, van Hemert, & Penninx, 2018; Topper, Molenaar, Emmelkamp, & Ehring, 2014).

However, prior SEM studies vary in the composition of RNT measures included in the models. RNT measures can be subdivided into content-dependent and content-independent measures. Content-dependent measures assess RNT with respect to (disorder-)specific thought content (e.g., rumination as in RNT about one's own depressed mood). Content-independent measures, in contrast, measure characteristic process features of RNT such as repetitiveness and intrusiveness of thinking regardless of the specific thought content. Whereas all SEM studies mentioned above included at least two content-dependent measures (typically one for rumination and one for worry), only few studies to date additionally incorporated content-independent measures of RNT, such as the Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011), and the Repetitive Thinking Questionnaire (RTQ; McEvoy, Mahoney, & Moulds, 2010) in their models (Samtani et al., 2021; Spinhoven et al., 2015; Spinhoven et al., 2018). Notably, while the content-dependent rumination and worry measures consistently loaded on additional scale-specific factors on top of the common factor, content-independent RNT measures sometimes (Samtani et al., 2021) but not always (Spinhoven et al. 2015; Spinhoven et al., 2018) represented separate scale-specific factors within a bi-factor model. An overview of studies using SEM to investigate the structure of RNT as well as the studies' characteristics can be found in the Supplementary Material, Part A.

**Latent Factors of RNT as Predictors of Psychopathology**

Additionally, several SEM studies investigated whether the bi-factor model of RNT predicts psychopathological symptoms. Both studies in healthy samples (Hur et al., 2017; Samtani et al., 2021; Taylor & Snyder, 2021; Topper et al., 2014) as well as studies in individuals with current or previous mood disorder (Spinhoven et al., 2018) show that the bi-factor structure of RNT is predictive of current and future levels of depression and anxiety (even

when controlling for initial symptom levels in the case of longitudinal designs). However, while these studies consistently showed that the common RNT factor of the bi-factor model predicts psychopathology, findings are less consistent as to whether scale-specific facets of RNT measures are additionally related to depression and anxiety. Whereas some studies did not find additional significant paths between scale-specific factors and symptoms (Hur et al., 2017; Taylor & Snyder, 2021; Topper et al., 2014), other studies reported that the scale-specific factors significantly predicted depressive and/or anxiety symptoms on top of the common factor (Samtani et al., 2021; Spinhoven et al., 2015; Spinhoven et al., 2018). Of note, in studies that did show additional predictive power of scale-specific RNT factors the common factor still consistently accounted for a much larger amount of variance in symptoms. In addition, only one (cross-sectional) study to date found indication for specificity in that a rumination scale exclusively predicted depression and a worry scale exclusively predicted anxiety on top of a common RNT factor (Spinhoven et al., 2015). In sum, findings are largely supportive of a transdiagnostic conceptualization according to which different forms of RNT share a common process that explains most of the variance in the relationship between RNT and psychopathology (for an overview see, Supplementary Material, Part A).

**Aims of the current study**

This study aimed to replicate prior findings regarding the factor structure underlying RNT and the predictive power of a common vs. specific RNT factors for depressive and anxiety symptoms. While a number of prior studies investigated these questions, only three studies (based on two samples) (Samtani et al., 2021; Spinhoven et al., 2015; Spinhoven et al., 2018) included content-independent measures of RNT and only one of these three studies (Spinhoven et al., 2018) examined the association of latent RNT factors with later psychopathological symptoms using a longitudinal design. Hence, there is need for replication in longitudinal studies using content-dependent a well as content-independent RNT measures. In the current study, content-dependent and content-independent measures of RNT as well as depressive and anxiety symptom measures were administered twice separated by an interval of three months to a large community sample. A bi-factor model, a separate-factor model and a single-factor model were estimated to examine the latent factor structure of RNT. Based on prior findings, we predicted that the bi-factor model would best fit the data among the three models (H1). To address inconsistent prior findings on whether content-independent RNT measures are largely represented by the common factor or load on unique scale-specific factors, we explored whether

the content-independent RNT measures, PTQ and RTQ, represented separate scale-specific factors within the bi-factor model.

In addition, we examined the whether the common RNT factor and the scale-specific factors predicted relative increases of depression and anxiety over a 3-month interval. In line with previous studies, we hypothesized that the common RNT factor in the bi-factor model would significantly predict depression and anxiety (H2). As described above, prior studies reported inconsistent results regarding the relations between scale-specific factors within bi-factor models and psychopathological symptoms. Therefore, we explored whether the scale-specific factors of the administered RNT measures predicted depression and anxiety over and above the common RNT factor.

## Material and Methods

### Participants

Participants were recruited via PsyWeb (https://psyweb.uni-muenster.de/), a non-commercial online panel for individuals from the general population who are interested in participating in psychological research. Therefore, the sample size of this study was dependent on the pool size of the panel and response rate of the registered individuals. E-mails were sent to every registered user of PsyWeb (covering approximately 12,000 individuals). The e-mails included general information about the study and a link that led to the online questionnaires. In response to this invitation, 1,282 individuals provided informed consent and completed the first assessment (t1). All participants who had completed the first assessment were invited to the second assessment three months later (t2). Participants who did not consent to their data being analyzed or indicated that they did not answer the questions truthfully were excluded from the analysis. A total of 523 participants completed both assessments and were included in the analyses reported in this paper. Mean age of the final sample was 49.34 years (*SD* = 13.7). 64.8% of the sample was female. All participants were native German speakers. 76.67% of the sample had the highest German secondary education (12-13 years of schooling), 52.39% held an additional university degree.

### Measures

#### *Ruminative Response Scale (RRS)*

The RSS (Nolen-Hoeksema and Morrow, 1991; German version: Kuehner, Huffziger, & Nolen-Hoeksema, 2007) is a 22-item scale measuring the frequency of thinking about one's

own depressive symptoms. 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 Likert scale ranging from 1 (“almost never”) to 5 (“almost always”). The RRS has been shown to have high internal consistency, test-retest reliability and high construct validity (Just & Alloy, 1997). In the current study, the 10-item version of the RRS – RRS-SF (Treynor, 2003) was administered. However, due to a technical error, four items of the RRS-SF (item 1,3, 8 and 10) were overwritten by other items so that we could not use them in the data analysis. The commonly used brooding and reflection subscale could not be computed as items 1,3 and 8 belong to the brooding and item 10 belongs to the reflection sub-scale (for the formulation of the lost items, see Supplementary Material, Part B). Therefore, a rumination scale consisting of RRS-SF items 2, 4, 5, 6, 7 and 9 was used in the statistical analysis. Cronbach’s α of this adapted rumination scale was satisfactory with .75 at the first timepoint.

***Penn State Worry Questionnaire (PSWQ)***

The PSWQ (Meyer, Miller, Metzger, and Borkovec, 1990; German version: Stöber, 1995) is a 16-item questionnaire assessing the frequency, intensity, and uncontrollability of worry. Respondents are asked to rate the items such as “Many situations make me worry” on a 5-point Likert scale ranging from 1 (“not typical at all of me”) to 5 (“very typical of me”). The PSWQ demonstrated high internal consistency with α ranging between .88 and .95 as well as good convergent and discriminative validity (Meyer, Miller, Metzger, & Borkovec, 1990). Research examining the factor structure of the PSWQ identified two underlying factors (van Rijsoort, Emmelkamp, & Vervaeke, 1999). However, the second factor, which exclusively consists of negatively worded items, has been considered as a statistical artefact rather than an actual factor (Brown, 2003). Therefore, in the current study, an 11-item version of the PSWQ was administered consisting of only the positively worded items of the original version (Hazlett-Stevens, Ullman, & Craske, 2004). In the current study, Cronbach’s α for the PSWQ (11-item version) was .95 at the first timepoint.

***Repetitive Thinking Questionnaire (RTQ)***

The RTQ (McEvoy et al., 2010; German version: own translation approved by the original author of the questionnaire) is a 31-item questionnaire that measures RNT as a thought process regardless of disorder-specific thought contents. Items were originally derived from several existing content-dependent measures of RNT. To reduce model complexity, a short version (RTQ-10) comprising only the 10 highest loading items of the RTQ was used in

this study. The RTQ-10 has been shown to be highly correlated with the full version (McEvoy et al., 2010). Respondents are asked to rate the items such as "once I started thinking about the situation, I couldn't stop" on a 5-point Likert scale ranging from 1 ("not true at all") to 5 ("very true"). The RTQ-10 demonstrated excellent internal consistency with Cronbach's α = .91 (Wong, McEvoy, & Rapee, 2015) as well as good construct validity (Mahoney, McEvoy, & Moulds, 2012). In the current study, Cronbach's α of the RTQ was .93 at the first timepoint.

***Perseverative Thinking Questionnaire (PTQ)***

The PTQ (Ehring et al., 2011; German version: Ehring et al., 2011) is a 15-item questionnaire assessing an individual's general tendency towards repetitive negative thinking. Like the RTQ, the PTQ measures process features of RNT rather than specific thought contents. Items such as "Thoughts intrude into my mind" are rated on a 5-point Likert scale ranging from 0 ("never") to 4 ("almost always"). Next to a general RNT factor, factor analyses have identified three sub-factors for the PTQ - (a) core characteristics, (b) unproductivity of RNT and (c) mental capacity captured by RNT. The total scale and the three subscales demonstrated excellent internal consistency (α ranging from .87 - .94) as well as high correlations with measures of depression and anxiety (Ehring et al., 2011). In the current study, Cronbach's α of the PTQ total scale was .96 at the first timepoint.

***Mood and Anxiety Symptom Questionnaire (MASQ)***

The MASQ (Watson et al., 1995; German version: Rad, 2011) consists of 90 items that measure anxiety and depressive symptoms. Respondents are asked to rate to which extent they had experienced each symptom on a 5-point Likert scale ranging from 1 ("not at all") to 5 ("extremely"). In the current study, the abbreviated 60-item version of the MASQ was administered and only the subscales "general distress anxiety" (11 items) and "depression" (12 items) were used in the data analysis. Both scales were shown to have excellent internal consistency with α ranging between .85 and .95 (Watson et al., 1995). In the current study, Cronbach's α for the "depression" scale was .94 at the first timepoint and .95 at the second timepoint. Cronbach's α for the "general distress anxiety" scale was .86 at the first timepoint and .88 at the second timepoint.

**Procedure**

All participants provided written informed consent before taking part in the study. The study comprised two identical online assessments at a distance of three months, in which

participants completed the measures described above. The survey was offered via the Unipark platform (http://www.unipark.com). Participants were not reimbursed.

### Data Analysis

We conducted confirmatory factor analyses (CFAs) to compare three different models: (1) a single-factor model assuming that all PTQ, RTQ, PSWQ and RRS items are indicators of one common factor, (2) a separate-factor model specifying that PTQ, RTQ, PSWQ and RRS items load on four separate scale-specific factors with no additional higher-order factor, and (3) a bi-factor model assuming that all items of all RNT scales are indicators of a common factor and at the same time load on respective scale-specific factors. Furthermore, we fit SEMs to investigate the usefulness of each of these models in the prediction of depression and anxiety three months later while controlling for initial symptoms (see Figure 2. Bi-factor model of RNT, Figure 3. Separate-factor model of RNT and Figure 4. Single-factor model of RNT). Goodness of fit of the models was assessed based on the comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residuals (SRMR). For the TLI and CFI, values between 0.90 and 0.95 are considered as acceptable, and > 0.95 as good. For the RMSEA and SRMR, values of < 0.08 are considered as acceptable, and values of < 0.05 as good (Hu & Bentler, 1999). Nested models were compared via Akaike information criterion (AIC) and sample-size adjusted Bayesian information criterion (BIC). All analyses were conducted in R (R Development Core Team, 2019). SEMs (including the CFAs) were fit using the R package lavaan (Rosseel, 2021).

## Results

### Correlations Between Measures of RNT and Symptom Measures

Table 1 shows means and standard deviations of as well as correlations between all measures of RNT and symptom measures (sum scores) used in the final analyses. All measures were significantly positively correlated with each other.

### CFA: Measures of RNT at t1

For the bi-factor model, goodness of fit was acceptable on the CFI, TLI and RMSEA, and good on the SRMR, $\chi^2(777) = 2113.51$, $p < .001$, CFI = .93, TLI = .92, RMSEA = .06, SRMR = .04. Compared to the bi-factor model, the single-factor model, $\chi^2(819) = 4519.50$, $p < .001$, CFI = .80, TLI = .788, RMSEA = .10, SRMR = .06, and the separate-factor model, $\chi^2(813) = 2680.11$, $p < .001$, CFI = .89, TLI = .89, RMSEA = .07, SRMR = .05, demonstrated

a poorer fit on all fit indices. In line with this, AIC and BIC demonstrated lower values and therefore indicated better fit of the bi-factor model (AIC = 49857.24, BIC = 49993.10) compared to the separate-factor model (AIC = 50351.85, BIC = 50449.53) and the single-factor model (AIC = 52179.23, BIC = 52270.40).

In the bi-factor model, all loadings on the common factor were significant and positive (for details, see Supplementary Material). Of note, 8 out of the 15 PTQ items, but only 1 of the RTQ and none of the PSWQ and RRS items showed loadings >.80 on the common factor. All loadings on the specific RTQ, PSWQ and RRS factors were significant and positive, whereas the PTQ factor only had 11 out of 15 significant loadings and 4 out of the 11 significant loadings were negative. Loadings on the scale-specific factors were generally smaller than loadings on the common factor. For example, none of the loadings on the scale-specific factors was >.80 (see Supplementary Material, Part C, for more details).

To further explore the relative goodness of fit of the bi-factor model, we tested two additional models, namely a reduced version of the bi-factor model without scale-specific factors for the content-independent measures as well as a second-order model. Both models demonstrated a poorer fit relative to the original bi-factor model (see Supplementary Material, Part D, for more details). Moreover, we cross-validated the original CFAs testing the relationship between measures of RNT in two subsets of the data that had not been used for the analyses reported in this section. These two cross-validations consistently confirmed the superiority of the bi-factor model as well as the robustness of the factor loadings within the bi-factor model (see Supplementary Material, Part E).

**Final SEMs: RNT Models (t1) Predicting Depression and Anxiety (t2)**

We examined the usefulness of all three RNT models (bi-factor, separate-factor, single-factor) in the prediction of depression and anxiety three months later. In all three models, we controlled for depression and anxiety at the first timepoint (see Figures 2-4 for a schematic illustration of the models). For theoretical reasons, we decided to let depression and anxiety covary at both timepoints. In the bi-factor and in the single-factor model, we let depression and anxiety at the first timepoint covary with the common RNT factor at the first timepoint. The bi-factor RNT model predicting sum scores on the subscales depression and general distress anxiety at the second time point demonstrated acceptable goodness of fit on the CFI, TLI and RMSEA and good goodness of fit on the SRMR, $\chi 2(953) = 2508.86$, $p < .001$, CFI = .92, TLI = .92, RMSEA = .06, SRMR = .04. Compared to the bi-factor model, the separate-factor RNT

model predicting depression and anxiety sum scores, $\chi 2(974) = 3309.60$, $p < .001$, CFI = .89, TLI = .88, RMSEA = .07, SRMR = .13, and the single-factor RNT model predicting depression and anxiety sum scores, $\chi 2(985) = 4892.49$, $p < .001$, CFI = .81, TLI = .80, RMSEA = .09, SRMR = .06, showed worse fit on all fit indices. In line with this, AIC and BIC demonstrated lower values and therefore indicated better fit of the bi-factor model (AIC = 63193.16, BIC = 63351.62) compared to the separate-factor model (AIC = 63915.90, BIC = 64032.03) and the single-factor model (AIC = 65476.79, BIC = 65580.99).

Table 2 shows the relationship between the different factors and depression/ anxiety in the bi-factor model. When controlling for baseline levels of symptoms, the common factor (C-RNT) significantly predicted depressive and anxiety symptoms three months later. On top of the common factor, the RTQ factor significantly predicted anxiety symptoms and the PSWQ factor significantly predicted depressive and anxiety symptoms. In contrast, the RRS factor and the PTQ factor did not significantly explain variance in symptoms on top of the common factor.

## Discussion

The first aim of the current study was to investigate the latent structure of RNT, which was assessed using both content-dependent and content-independent measures. In line with our first hypothesis, a bi-factor model assuming that items of all RNT measures are indicators of both a common factor as well as scale-specific factors best explained the latent factor structure of RNT. Thereby, our results replicate the findings of several prior SEM studies (Hur et al., 2017; Samtani et al., 2021; Spinhoven et al., 2018; Taylor & Snyder, 2021; Topper et al., 2014) and fit with qualitative descriptions of unique aspects (e.g. temporal orientation; Beck et al., 1987; Beck & Perkins, 2001) vs. common aspects of RNT (i.e., shared process features; Ehring & Watkins, 2008; Ehring et al., 2011; Kaplan et al., 2018; Segerstrom et al., 2003; Wahl et al., 2019) . The fact that the common factor explained the vast amount of systematic variance in all RNT measures strongly supports transdiagnostic conceptualizations of RNT (Ehring & Watkins, 2008; Watkins, 2008; Watkins & Roberts, 2020).

Only few studies to date have included content-dependent measures of worry and rumination as well as content-independent measures of RNT when investigating a bi-factor model. We therefore specifically explored the factor loadings of the content-independent measures more closely. Of note, the items of the PTQ showed the highest loadings on the common factor and at the same time the lowest and most inconsistent loadings on their scale-specific factor. This suggests that thought process features such as repetitiveness, intrusiveness

and unproductivity of the thoughts measured by the PTQ (Ehring et al., 2011) might be important elements of the common factor. In contrast, the RTQ, which was also developed to measure process rather than content features of RNT, demonstrated smaller loadings on the common factor and higher loadings on its scale-specific factor. The difference in factor loadings between the RTQ and PTQ can possibly be explained by differences in the conceptual basis of the two questionnaires. First, the instruction of the PTQ asks participants to rate how they typically respond to negative experiences or problems. In the RTQ, respondents are asked to remember specific situations in which they had felt distressed or concerned and to answer the items in relation to these particular situations. Second, the RTQ, in contrast to the PTQ, was based on a re-analysis of items included in earlier content-dependent questionnaires. It is therefore conceivable that the PTQ may be a purer measure of the content-independent process features of RNT than the RTQ. However, since to our knowledge only one prior study (Samtani et al., 2021) combined PTQ and RTQ with content-dependent measures of RNT in a bi-factor model, these results need to be interpreted with caution.

The second aim of our study was to test the usefulness of the derived latent RNT factors in predicting future levels of depression and anxiety. Consistent with our second hypothesis and in line with prior studies (Spinhoven et al., 2018; Taylor & Snyder, 2021; Topper et al., 2014), the common RNT factor of the bi-factor model significantly predicted depression and anxiety three months later while controlling for baseline symptoms.

Whereas the common factor in bi-factor models has consistently been found to predict depression and anxiety in prior studies, evidence on the relationship between unique variance in single measures of RNT and psychopathology is less consistent. We therefore aimed to explore whether the scale-specific factors predicted depression and/or anxiety symptoms over and above the common factor. Results showed that the PSWQ factor predicted both depressive and anxiety symptoms and the RTQ factor significantly predicted anxiety symptoms. However, the PTQ and the RRS factors did not significantly predict future symptomatology in addition to the common factor. The fact that two of the other scale-specific RNT factors predicted future symptomatology suggests that the common factor may not capture all aspects of RNT that are relevant for the development and maintenance of symptoms. One such aspect could be thought content. However, if content was a crucial additional feature of RNT related to psychopathology, one would expect some specificity with worry being mainly related to anxiety symptoms and depressive rumination being related to depressive symptoms. In contrast, in the current study the scale-specific factor representing worry predicted both depression and

anxiety, whereas the scale-specific factor representing depressive rumination predicted neither symptom scale. Similarly, earlier research is inconsistent in this regard, indicating either no additional connections between scale-specific factors (of a bi-factor model) and symptoms (Hur et al., 2017; Taylor & Snyder, 2021; Topper et al., 2014) or different patterns to the one found in the current study (Samtani et al., 2021; Spinhoven et al., 2015; Spinhoven et al., 2018).

One reason for the inconsistencies could be that although there may be features of RNT in addition to the common RNT factor that are relevant for the development and maintenance of psychopathology, these may not be represented well by scale-specific latent variables. For example, a recent study used a data-driven method to disentangle a number of dimensions of RNT, including dyscontrol, self-focus, and valence (Hallion et al., 2022). Modeling these dimensions as latent variables could be a promising alternative to modeling scale-specific latent factors and might help to identify important unique features of RNT.

**Limitations**

The present study had several limitations. Firstly, as in prior SEM studies using self-report measures there is no certainty that scale-specific RNT factors actually reflect unique aspects of certain forms of RNT, such as a particular thought content associated with worry or rumination. Instead of capturing the constructs of interest, the scale-specific factors might reflect methodological variance between the different measures (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Secondly, the present study only covered some forms of RNT and mental health problems associated with RNT. In addition to worry and rumination, RNT can for example also occur in the form of post-event processing (Rachman, Gruter-Andrew, & Shafran, 2000). Moreover, a range of mental health problems beyond depression and anxiety such as disordered eating behavior (Smith, Mason, & Lavender, 2018) and posttraumatic stress symptoms (Szabo, Warnecke, Newton, & Valentine, 2017) are associated with RNT. Future research should incorporate additional RNT and psychopathology measures. Third, generalizability of the current findings to clinical populations is limited since we tested a non-clinical sample. Fourth, due to a technical failure we were unable to use 4 of the 10 RRS items and therefore could not include separate factors for the RRS subscales “brooding” and “reflection” in the SEMs. This might have contributed to the non-significant paths between the RRS-RNT factor and symptoms. Indexing the rumination factor exclusively by the “brooding” items might have led to slightly different results as the “brooding” subscale was shown to consistently and positively predict psychopathology, whereas the relationship was found to be less consistent and sometimes even negative for the “reflection” subscale (Treynor, 2003).

### Conclusions

Despite these limitations, the current findings bear important implications for future research and ultimately even clinical practice. The finding that a bi-factor model outperformed both a separate- and a single-factor model in explaining the latent factor structure of RNT and predicting depression and anxiety implies that it is useful to combine different measures of RNT. In this way, it is possible to capture both common and unique aspects of RNT. The high loadings of the PTQ items on the common RNT factor suggest that administering content-independent RNT measures such as the PTQ could be a less time-consuming, more feasible alternative way to measure common (transdiagnostic) aspects of RNT (as opposed to the SEM approach i.e., indexing a common latent RNT factor through several different RNT measures). Finally, the fact that the common RNT in the present study - in line with a growing body of SEM studies – predicted depression and anxiety while controlling for baseline symptoms highlights the role of RNT in the development and maintenance in different types of psychopathology and the resulting need to address RNT in the assessment and treatment of mental disorders. A number of relatively recent forms of psychological treatment, such as rumination-focused cognitive-behavioral therapy (Watkins, 2016) and metacognitive therapy (Wells, 2011), put a focus on the assessment and reduction of RNT. The current results underline their potential as effective transdiagnostic treatments.

## Declarations

### Conflict of interest

The authors declare that they have no conflict of interest.

### Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the ethics committee of the Department of Psychology and Educational Science of Ludwig-Maximilians-University Munich, Germany.

### Consent to participate

Informed consent was obtained from all individual participants included in the study. All participants included in the final data set signed informed consent regarding publishing their anonymized data arising from this study.

### Data availability statement

The datasets generated and analyzed during the current study are available in the Open Science Framework (OSF) repository, https://osf.io/ytep7/.

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**Table 1**

*Bivariate correlations*

| | *M*(*SD*) | PSWQ t1 | RRS t1 | PTQ t1 | RTQ t1 | D t1 | D t2 | GDA t1 |
|---|---|---|---|---|---|---|---|---|
| PSWQ t1 | 28.68 (10.41) | | | | | | | |
| RRS t1 | 12.51 (3.70) | .58 | | | | | | |
| PTQ t1 | 27.68 (13.20) | .77 | .65 | | | | | |
| RTQ t1 | 26.88 (9.67) | .76 | .69 | .86 | | | | |
| D t1 | 23.32 (10.56) | .62 | .59 | .65 | .66 | | | |
| D t2 | 22.44 (10.81) | .60 | .54 | .59 | .62 | .77 | | |
| GDA t1 | 20.78 (7.65) | .61 | .50 | .57 | .60 | .72 | .62 | |
| GDA t2 | 20.73 (7.78) | .60 | .48 | .56 | .62 | .63 | .76 | .74 |

*Note.* RRS = Ruminative Response Scale; PSWQ = Penn State Worry Questionnaire; PTQ = Perseverative Thinking Questionnaire; RTQ = Repetitive Thinking Questionnaire; GDA = Mood and anxiety questionnaire, subscale “general distress anxiety”; D = Mood and Anxiety Questionnaire, subscale “depression”; t1 = timepoint 1; t2 = timepoint 2; all correlations were significant with $p < .001$.

**Table 2**

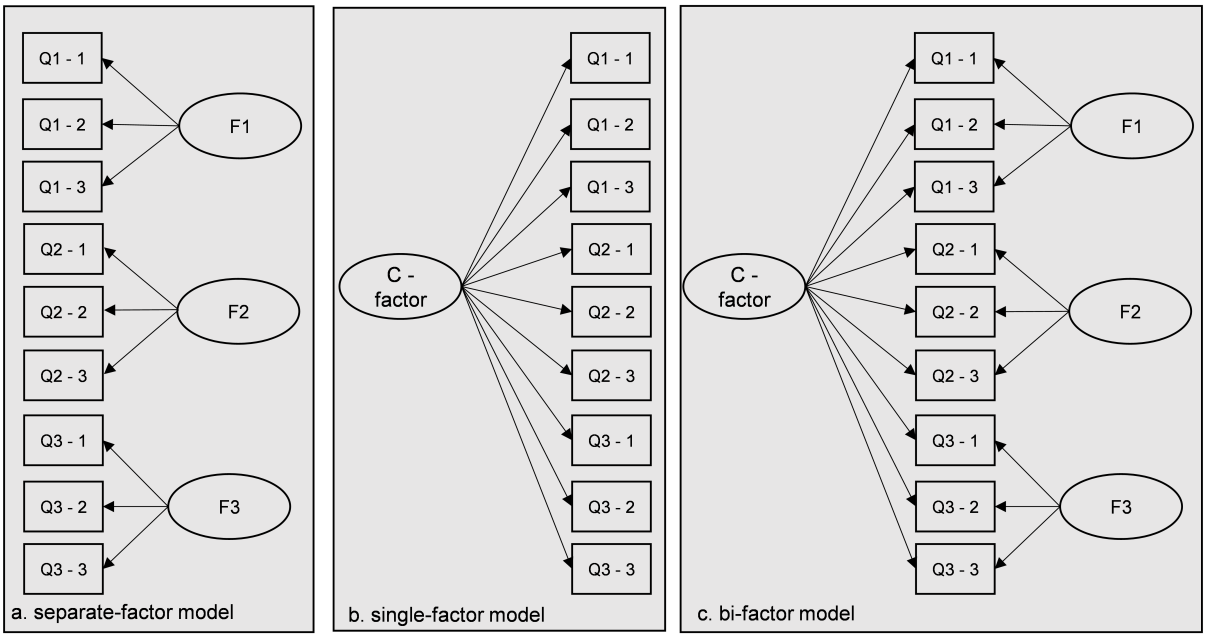
*Bi-factor model regressions*

| | ***Est.*** | ***SE*** | ***z*** | ***Pr(>\|z\|)*** | ***Std.lv*** | ***Std.all*** |
|---|---|---|---|---|---|---|
| GDA t2~ | | | | | | |
| C-factor t1 | 2.68 | 0.35 | 7.54 | .000 | 2.11 | .28 |
| PTQ-factor t1 | -0.18 | 1.88 | -0.10 | .925 | -0.02 | -.00 |
| RTQ-factor t1 | 2.97 | 0.91 | 3.27 | .001 | 0.10 | 0.13 |
| PSWQ-factor t1 | 2.02 | 0.62 | 3.28 | .001 | 0.81 | .11 |
| RRS-factor t1 | 0.39 | 0.43 | 0.90 | .370 | 0.23 | .03 |
| GDA t1 | 0.53 | 0.03 | 16.53 | .000 | 0.53 | 0.53 |
| Depression t2~ | | | | | | |
| C-factor t1 | 3.19 | 0.50 | 6.41 | .000 | 2.56 | .24 |
| PTQ-factor t1 | -0.74 | 2.55 | -0.29 | .772 | -0.10 | -.01 |
| RTQ-factor t1 | 1.46 | 1.09 | 1.34 | .181 | 0.49 | .05 |
| PSWQ-factor t1 | 3.19 | 0.84 | 3.79 | .000 | 1.28 | .12 |
| RRS-factor t1 | 0.44 | 0.58 | 0.76 | .450 | 0.27 | .03 |
| Depression t1 | 0.57 | 0.03 | 16.92 | .000 | 0.57 | .57 |

*Note*. C-factor = common RNT factor; RRS-factor = scale-specific factor of the Ruminative Response Scale; PSWQ-factor = scale-specific factor of the Penn State Worry Questionnaire; PTQ-factor = scale-specific factor of the Perseverative Thinking Questionnaire; RTQ-factor = scale-specific factor of the Repetitive Thinking Questionnaire; GDA = Mood and anxiety questionnaire, subscale “general distress anxiety”; Depression = Mood and Anxiety Questionnaire, subscale “depression”; t1 = timepoint 1; t2 = timepoint 2.

**Figure 1**

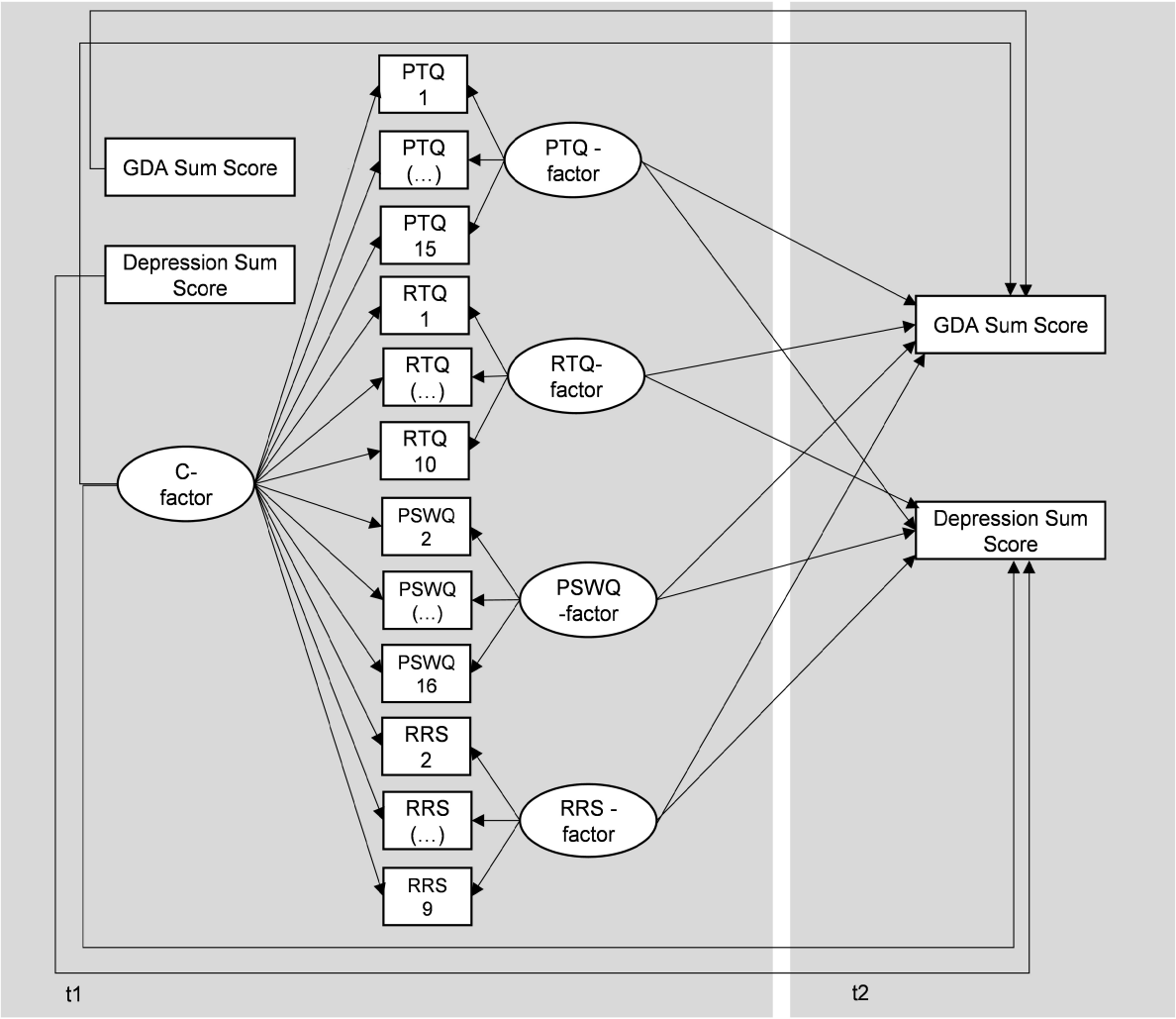
*Example factor models of RNT*




*Note.* Q1 = RNT questionnaire 1; Q2 = RNT questionnaire 2; Q 3 = RNT questionnaire 3; F1-3 = Scale-specific factors for the different RNT questionnaires; C-factor = common factor for all RNT questionnaires; 1/2/3 = single items of the different RNT questionnaires.

**Figure 2**

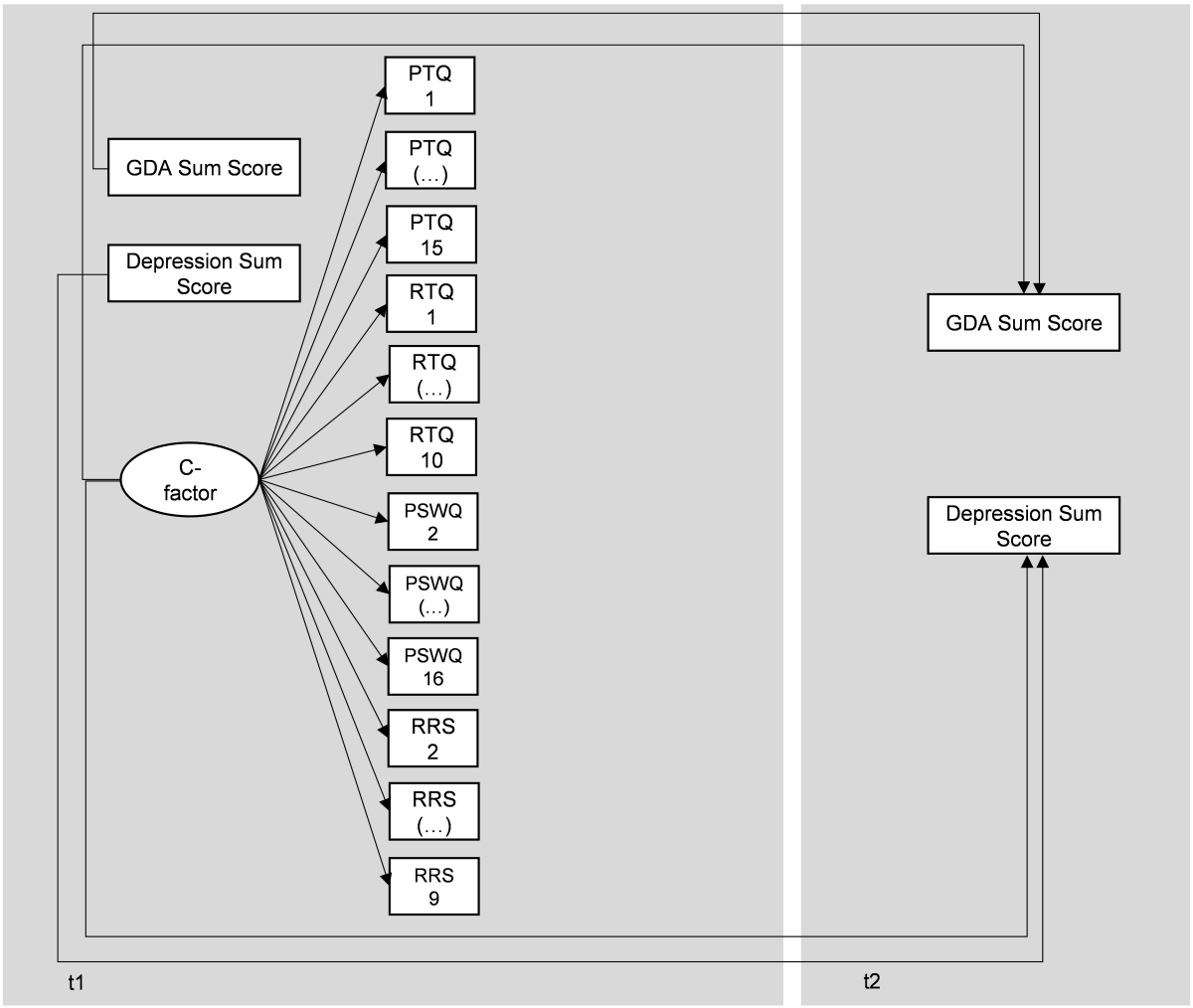
*Bi-factor model of RNT*




*Note*. C-factor = common RNT factor; RRS =Ruminative Response Scale; PSWQ = Penn State Worry Questionnaire; PTQ = Perseverative Thinking Questionnaire; RTQ = Repetitive Thinking Questionnaire; GDA = Mood and anxiety questionnaire, subscale "general distress anxiety"; Depression = Mood and Anxiety Questionnaire, subscale "depression".

**Figure 3**

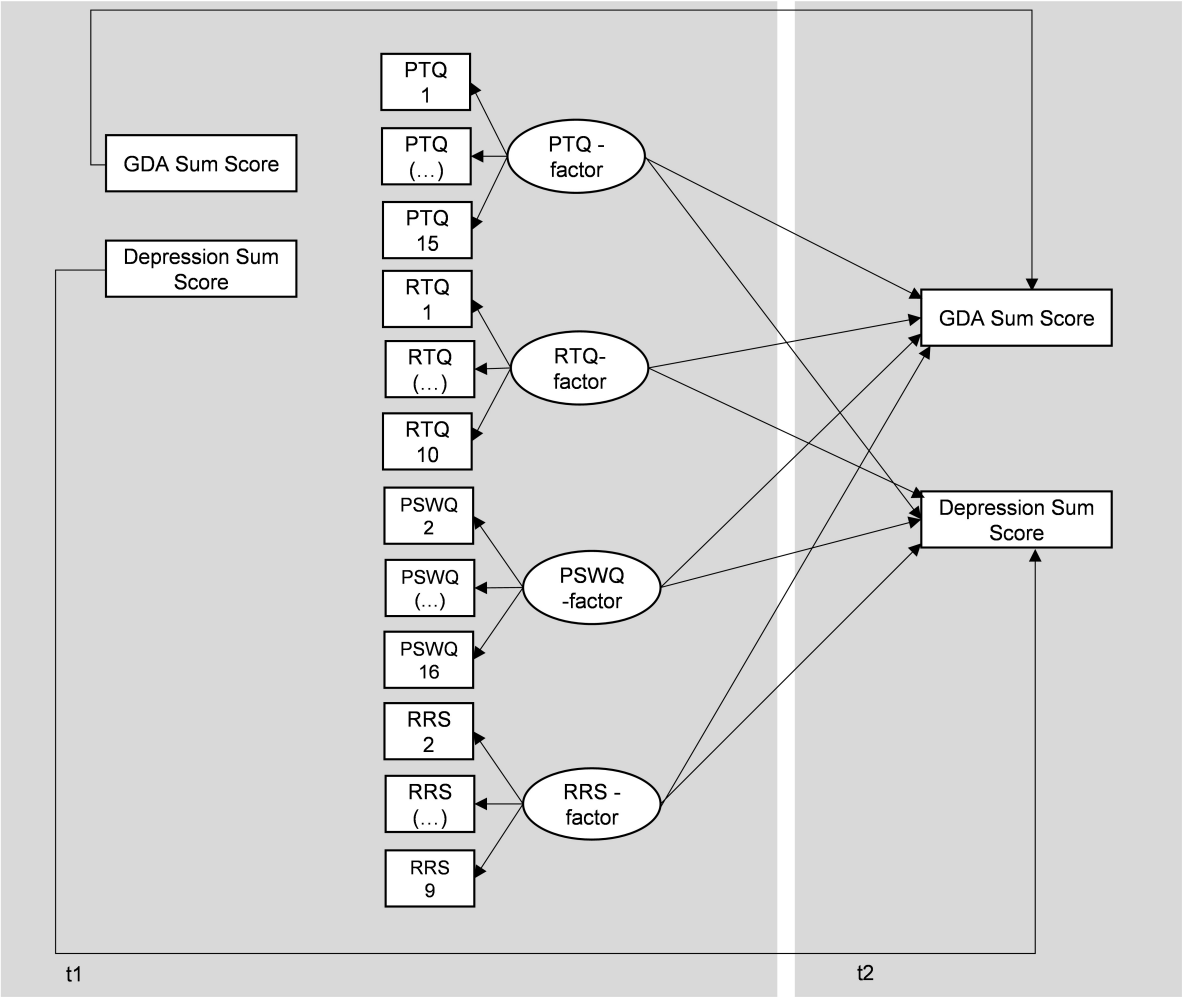
*Single-factor model of RNT*




*Note*. C-factor = common RNT factor; RRS =Ruminative Response Scale; PSWQ = Penn State Worry Questionnaire; PTQ = Perseverative Thinking Questionnaire; RTQ = Repetitive Thinking Questionnaire; GDA = Mood and anxiety questionnaire, subscale "general distress anxiety"; Depression = Mood and Anxiety Questionnaire, subscale "depression".

**Figure 4**

*Separate-factor model of RNT*




RRS =Ruminative Response Scale; PSWQ = Penn State Worry Questionnaire; PTQ = Perseverative Thinking Questionnaire; RTQ = Repetitive Thinking Questionnaire; GDA = Mood and anxiety questionnaire, subscale "general distress anxiety"; Depression = Mood and Anxiety Questionnaire, subscale "depression".

# 3. Study II:

*An Ecological Momentary Assessment Study Assessing Repetitive Negative Thinking as a Predictor for Psychopathology*

This chapter is a pre-peer-review, pre-copyedit version of an article submitted for publication at *Clinical Psychological Science*.

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## Abstract

Repetitive negative thinking (RNT), an important transdiagnostic process, is commonly assessed using trait questionnaires. While these instruments ask respondents to estimate their general tendency towards RNT, ecological momentary assessment (EMA) allows to assess how much individuals actually engage in RNT in their daily lives. In a sample of $N$ = 1,176 adolescents and young adults, we investigated whether average levels of RNT assessed via EMA predicted psychopathological symptoms. Controlling for trait RNT measures and baseline scores on outcome measures, we found that average levels of RNT assessed via EMA significantly predicted higher depressive and anxiety symptoms as well as lower mental well-being at baseline, one-, three-, and twelve-month follow-up. Exploratory analyses of the association between temporal dynamics of RNT (e.g., RNT inertia) and psychopathological symptoms yielded inconsistent results. The high predictive power of average scores on the EMA-based RNT measure suggests that EMA is a promising tool for assessing RNT.


**Keywords**: Repetitive Negative Thinking, Ecological Momentary Assessment, Depression, Anxiety

# Introduction

Repetitive negative thinking (RNT), a widely studied transdiagnostic process, is a style of thinking focused on negative content and experienced as intrusive and difficult to disengage from (Ehring & Watkins, 2008; Watkins & Roberts, 2020). It can for example occur in the form of depressive rumination (Nolen-Hoeksema, 1991) or worrying about the future (Borkovec et al., 1983). Traditionally, researchers have used trait questionnaires to investigate RNT or retrospective questionnaires assessing RNT during a defined interval (e.g., Ehring et al., 2011; McEvoy et al., 2010; Meyer et al., 1990; Nolen-Hoeksema & Morrow, 1991). Thus, these questionnaires ask respondents to provide an estimate of their general tendency towards RNT or to indicate how much they engaged in RNT over a certain period of time (e.g., past days, weeks, months). Numerous studies have found that patients with mental disorders, such as depression or anxiety disorders, score higher on these trait RNT questionnaires than healthy controls (e.g., Arditte Hall et al., 2019; Arditte et al., 2016; Watkins & Roberts, 2020). Additionally, high scores on trait RNT measures have consistently been found to predict the development of future mental health problems (e.g., Funk et al., 2022; Spinhoven et al., 2018; Whisman et al., 2020; Wild et al., 2016). Furthermore, a study on RNT across the life span specifically highlighted the role of RNT in adolescents' and young adults' mental health, showing that scores on a trait RNT measure peaked in young adulthood (Lilly et al., 2023).

While studies using trait questionnaires have advanced our understanding of RNT by demonstrating that it is an important factor in the etiology of various mental disorders, measuring RNT via trait questionnaires also has limitations. Importantly, trait measures might by biased by time (retrospective recall) and could reflect metacognitive beliefs about RNT instead of capturing how much a person actually engages in RNT in their daily life (Conner & Barrett, 2012; Ebner-Priemer & Trull, 2009; Schwarz et al., 2009; Seizer et al., 2024). A recent review specifically raised concerns about using trait instruments to assess processes such as RNT in adolescents and young adults as cognitions and emotions underly strong temporal fluctuations in these age groups (Thunnissen et al., 2022).

## Ecological Momentary Assessment of RNT

In order to overcome limitations of traditional measures and increase ecological validity in the assessment of RNT, recent studies employed ecological momentary assessment (EMA) (Connolly & Alloy, 2017; Hjartarson et al., 2022; Pasyugina et al., 2015; Rosenkranz et al., 2020; Ruscio et al., 2015; Thielsch et al., 2015; Timm et al., 2017). EMA is an increasingly

popular method used to assess psychological processes in (nearly) real time (Csikszentmihalyi & Larson, 1984; Shiffman et al., 2008), for example via participants' smartphones. In EMA studies measuring RNT, participants are instructed to repeatedly fill out short surveys on how much they currently engage in worry, rumination, or repetitive thinking (Pasyugina et al., 2015; Rosenkranz et al., 2020). Notably, EMA studies have typically found only small to moderate correlations between average scores on EMA-based RNT measures and trait questionnaire measures of RNT (Connolly & Alloy, 2017; Hur et al., 2019; Rosenkranz et al., 2020), indicating that EMA and trait questionnaires assess different aspects of RNT. Moreover, first results suggest that EMA captures features of RNT that may be relevant to the development and maintenance of psychopathology. Specifically, average levels of RNT measured via EMA were found to predict a range of mental health outcomes such as depressive symptoms, anxiety symptoms as well as disordered eating behavior (Connolly & Alloy, 2017; Kornacka et al., 2021; Pasyugina et al., 2015; Rosenkranz et al., 2020; Timm et al., 2017). As such, EMA could help to better understand the relationship between RNT and poor mental health and appears particularly promising for increasing ecological validity of RNT assessment in adolescents and young adults.

**Value of EMA RNT Measures for the Prediction of Psychopathology**

Despite its potential, it is not yet clear how much additional value assessing RNT using EMA holds for the prediction of psychopathology. That is, studies testing whether RNT measured via EMA predicts psychopathological symptoms while controlling for trait RNT questionnaires are still scarce and inconclusive. Connolly & Alloy (2017) found that average scores of stress-reactive rumination measured via EMA significantly predicted depressive symptoms when controlling for trait RNT measures. However, other studies either did not find effects of EMA-based RNT measures on psychopathological symptoms when controlling for trait RNT measures (Timm et al., 2017) or did not control for the effects of trait RNT measures in their analyses (Pasyugina et al., 2015; Rosenkranz et al., 2020; Ruscio et al., 2015). Similarly, studies investigating whether RNT measured via EMA predicts psychopathological symptoms at a later time point while controlling for the effect of baseline symptoms have yielded inconsistent results. Some (Connolly & Alloy, 2017; Rosenkranz et al., 2020; Sala et al., 2019) but not all studies (Ruscio et al., 2015; Timm et al., 2017) found that average scores of RNT measured via EMA predicted psychopathological symptoms when controlling for baseline symptomatology.

A possible reason for the discrepancies could be that earlier EMA studies have used different measures for momentary RNT. An important distinction between RNT measures (both trait questionnaires and items used for EMA assessment) is whether these are content-dependent or -independent. Some measures are content-dependent in that they assess RNT with respect to (disorder-)specific thought content. Examples are the Ruminative Response Scale (Nolen-Hoeksema & Morrow, 1991), which measures the extent to which individuals engage in rumination about their own sad mood, or the Penn State Worry Questionnaire (Meyer et al., 1990) assessing worrying about the future. In contrast, content-independent RNT measures (e.g., the Perserverative Thinking Questionnaire; Ehring et al., 2011) assess process features of RNT that are shared across different forms of RNT and independent of specific thought content, such as intrusiveness, repetitiveness or uncontrollability of thinking.

Most EMA studies to date have adapted different content-dependent trait RNT measures to assess momentary rumination or worrying in daily life (Connolly & Alloy, 2017; Hur et al., 2019; Pasyugina et al., 2015; Ruscio et al., 2015). However, adapting content-independent, i.e., process-focused, RNT measures could also be a promising avenue in EMA research. Content-dependent RNT measures have a narrower focus as they assess specific forms of RNT which characteristically affect individuals with particular types of psychopathology (e.g., worrying as a symptom of generalized anxiety disorder). In comparison, content-independent, process-focused RNT measures might be less confounded with certain symptom domains and can therefore be hypothesized to be more independent and better predictors of different mental health problems. In line with this notion, studies investigating shared and unique aspects of rumination and worrying suggest that shared components reflecting process features of RNT are a better predictor of both depressive and anxiety symptoms than unique ones (Funk et al., 2022; McEvoy et al., 2018; Samtani et al., 2021; Topper et al., 2014). In a recent study, we therefore adapted the Perseverative Thinking Questionnaire (PTQ) – a content-independent process-focused trait RNT measure – to assess momentary RNT in daily life (Rosenkranz et al., 2020). The new PTQEMA consists of four items measuring repetitiveness, intrusiveness, and uncontrollability of thinking as well as the distress related to the thinking process and has demonstrated good psychometric properties. In addition, high average scores on this EMA-based RNT measure predicted higher depressive, anxiety and stress symptoms when controlling for baseline symptoms (Rosenkranz et al., 2020). The first aim of the current study was to investigate whether the EMA-based RNT measure also predicts psychopathology when

controlling for established trait RNT measures (in addition to controlling for baseline symptomatology).

**Fluctuations in RNT as a Predictor of Psychopathology**

In addition to providing a better estimation of the frequency and severity of RNT in daily life, EMA provides an excellent means of recording temporal dynamics of RNT. Investigating fluctuations in RNT over time could improve understanding of how RNT leads to a deterioration of mental health. In fact, several theoretical concepts of RNT make assumptions about the temporal dynamics of the process. The habit account of RNT proposes, for example, that RNT initially occurs as a goal-directed attempt to mentally solve problems but then becomes maladaptive by turning into a mental habit that is rigidly triggered in various settings (Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020). Moreover, RNT has been classified as a dysfunctional emotion regulation strategy that contributes to psychopathology when used in an inflexible and rigid manner (Aldao et al., 2015; Lincoln et al., 2022). Hence, theoretical accounts of RNT assume that RNT is especially maladaptive when inert and resistant to change over time, that is, when a person gets "stuck" in negative thought spirals.

In EMA research, three indices are commonly used to estimate how psychological processes fluctuate over time: inertia, variability, and instability (Bos et al., 2019; Houben et al., 2015; Jahng et al., 2008). Inertia is formally defined as the first-order autocorrelation of processes assessed repeatedly (Brose et al., 2015; Koval et al., 2012; Kuppens et al., 2012; Suls et al., 1998). Thus, high inertia of RNT reflects a high temporal dependency of the repeatedly assessed RNT scores, with scores at each time point being strongly predicted by those assessed at the preceding time point. Variability, on the other hand, is estimated by computing the within-person standard deviation (SD) of a process over time (Trull et al., 2015). High variability of RNT thus reflects a high magnitude of fluctuations in scores, meaning that a person showed both relatively high and low RNT scores over the measurement period relative to their mean RNT score. While inertia reflects temporal dependency and variability reflects the magnitude of fluctuations, the third index, instability, captures both components. Instability can be calculated by computing the root mean squared successive difference (RMSSD) of a time series (Jahng et al., 2008). High instability of RNT could either reflect high RNT variability, low RNT inertia, or a combination of both.

Prior EMA research has investigated all three indices to test how fluctuations in affect relate to psychopathology. Results point towards complex associations (Houben et al., 2015),

for example, showing that symptoms of mood disorders are associated with high inertia (Brose et al., 2015; Koval et al., 2012; Koval et al., 2013; Kuppens et al., 2012), both high (Bos et al., 2019; Koval et al., 2013) and low variability (Rottenberg, 2005), and high instability (Schoevers et al., 2021) of (particularly negative) affect. These seemingly contradictory findings may reflect the fact that the different fluctuation parameters describe different components of fluctuations in affect, for example, temporal dependency or magnitude of fluctuations. For example, both high temporal dependency of negative affect on a consistently low level (high inertia and low variability) and steadily increasing negative affect (high inertia and high variability) could be linked to psychopathology. Moreover, the complex picture is in line with theoretical accounts of emotion regulation proposing that both hyper- and insensitive affective reactions to changing contexts can be maladaptive (Kuppens & Verduyn, 2015).

While prior EMA studies have mainly explored how fluctuations in emotional states relate to mental health, theorical assumptions about temporal dynamics of RNT make it worthwhile to apply similar indices to RNT. Investigating RNT inertia, for example, would enable one to investigate the habit model of RNT according to which RNT is especially dysfunctional when inert and resistant to change, that is, when it has become a mental habit. However, only two studies to date have examined RNT fluctuations and their associations with psychopathology empirically (Bean et al., 2020; Bean et al., 2021). In these studies, high inertia of RNT was indeed positively associated with (residual) depressive symptoms in individuals with current or past depression (Bean et al., 2020) as well as with sub-clinical depressive symptoms in a healthy sample (Bean et al., 2021). Further studies are needed to test whether the findings regarding RNT inertia replicate. In addition, to get a nuanced understanding of which dynamic patterns of RNT can be dysfunctional, it appears promising to investigate all three commonly used fluctuation indices (inertia, variability and instability) based on EMA RNT data within one sample.

**Study Aims**

EMA promises to increase ecological validity in the assessment of RNT, particularly in young age groups. However, it is not yet clear how much value measuring RNT via EMA provides for the prediction of psychopathology. In the current study, we aimed to investigate whether the new content-independent EMA-based RNT measure (PTQEMA) developed by Rosenkranz et al. (2020) longitudinally predicts mental health outcomes in a pan-European sample of adolescents and young adults. Specifically, we hypothesized that average scores on

the PTQEMA would predict current and later depressive and generalized anxiety symptoms as well as reduced mental well-being when controlling for the effects of established trait RNT measures and baseline scores on the corresponding outcome measure. Our secondary aim was to explore the link between fluctuations in RNT during the EMA phase and mental health. As there is only a small number of prior studies, none of which has tested different fluctuation indices within the same sample, no a-priori hypotheses were tested. Instead, we investigated the effects of RNT inertia, variability, and instability on psychopathological symptoms and mental well-being in an exploratory way. We simultaneously tested the effects of RNT inertia and variability on depressive symptoms, generalized anxiety symptoms, and mental well-being to differentiate between the impact of temporal dependencies and magnitude of fluctuations in RNT. In separate models, we investigated the effect of instability - as a combined index of temporal dependency and variability - on depressive symptoms, generalized anxiety symptoms, and mental well-being.

## Transparency and Openness

The current study was not preregistered. Data, codebook, and analytic code can be found on the Open Science Framework platform (OSF; https://osf.io/dm2ab/). We report all data exclusions, all manipulations, and all measures in the study. This study involved an analysis of data from the ECoWeB (emotional competence for well-being in young adults) cohort multiple randomized controlled trial (cmRCT) (Newbold et al., 2020): Our sample size was determined by the number of participants completing an EMA assessment as part of two parallel randomized controlled trials within the ECoWeB cmRCT. Data was collected online in four countries (Belgium, Germany, Spain, United Kingdom). All study procedures were approved by the Ethics Committees of all trial sites before data collection began (Universitat Jaume I de Castellon, Spain, 14 May 2019, reference number CD/023/2019; LMU Munich, Germany, 4 September 2019, reference number 19-468, 19-315; University of Exeter, 23 July 2019, reference number eCLESPsy000048 v3.0; University of Ghent, Belgium, 17 October 2019, reference number 2019-1069). The study procedure is in accordance with the declaration of Helsinki.

# Method

## Participants

The sample consisted of adolescents and young adults taking part in the ECoWeB cmRCT. (Newbold et al., 2020). Inclusion criteria were (1) age 16 to 22 years, (2) living in Belgium, Germany, Spain or the UK (3) fluency in at least one of Dutch, English, German or Spanish, (4) informed parental consent if under 18 years in Germany and Belgium and (5) regular access to an Android or iOS smartphone. Individuals with current or lifetime major depressive disorder, current use of antidepressants or psychological interventions, a history of psychosis, bipolar disorder, substance dependence or other severe psychiatric disorder, or current suicidality were excluded from participation. Details on recruitment can be found in the ECoWeB cmRCT study protocol (Newbold et al., 2020). As EMA data were available for a subset of $N$ = 1,776 participants of the full sample ($N$ = 3,794), all statistics reported hereafter pertain to this subset. Table 1 provides an overview of the demographic characteristics of the sample.

## Measures

All measures used in the current study were administered in validated versions in either English, Spanish, German or Dutch.

### *Trait Rumination*

The 5-item brooding subscale (Treynor et al., 2003) of the Ruminative Response Scale (RRS-B) was used as a measure of trait rumination. In the RRS, respondents are asked to indicate what they generally do when they feel sad, down or depressed. Respondents are instructed to rate items such as “When I feel sad, down or depressed, I think `What am I doing to deserve this?" on a 4-point scale ranging from 1 “almost never” to 4 “almost always”. The RRS-B subscale has demonstrated acceptable internal consistency and associations with current and later depressive symptoms (Treynor et al., 2003). Cronbach’s alpha in this sample ranged between .68 and .77.

### *Trait Worrying*

The Penn State Worry Questionnaire - Abbreviated (PSWQ-A; Hopko et al., 2003) was administered to assess trait worrying. In this 8-item questionnaire, respondents are instructed to answer items such as “Many situations make me worry” on a scale from 1 “not typical” to 5

"very typical". The measure has demonstrated high internal consistency, adequate test-retest reliability as well as good convergent and divergent validity (Hopko et al., 2003). In the current sample, Cronbach's alpha ranged between .91 and .93.

### *Depressive Symptoms*

As a measure of depressive symptoms, the Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001) was administered. The PHQ-9 asks respondents to indicate how much problems such as "little interest or pleasure in doing things" have bothered them in the last two weeks on a scale ranging from 0 "not at all" to 3 "nearly every day". The PHQ-9 is a widely used and well validated measures of depressive symptoms (Kroenke et al., 2001). Cronbach's alpha in the current study ranged between .73 and .83

### *Generalized Anxiety Symptoms*

General anxiety symptoms were assessed using the Generalized Anxiety Disorder-7 questionnaire (GAD-7; Spitzer et al., 2006). In the GAD-7, respondents are instructed to indicate how often problems such as "feeling nervous, anxious or on edge" have bothered them in the last two weeks on a scale from 0 "not at all" to 3 "nearly every day". The GAD-7 is a widely used measure for anxiety symptoms that demonstrated good psychometric properties (Spitzer et al., 2006). In the current sample, Cronbach's alpha ranged between .82 and .86.

### *Mental Well-being*

The 14-item Warwick-Edinburgh Mental Well Being Scale (WEMWBS; Tennant et al., 2007) was administered as a measure for mental well-being. Respondents are asked to rate how much experiences such as "I've been feeling optimistic about the future" applied to them in the last two weeks on a scale from 1 "none of the time" to 5 "all of the time". The WEMWBS is a well-validated scale with good psychometric properties (Stewart-Brown et al., 2011). Cronbach's alpha in the current sample ranged between .86 and .90.

### *EMA Measure of RNT*

To measure RNT in participants' daily life, we administered our recently developed 4-item Perseverative Thinking Questionnaire$_{EMA}$ (PTQ$_{EMA}$; Rosenkranz et al., 2020). The PTQ$_{EMA}$ is based on the Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) and assesses content-independent process features of RNT, i.e., (i) repetitiveness, (ii) intrusiveness, (iii) uncontrollability of thinking as well as (iv) distress associated with the thoughts.

Participants are instructed to rate the following four items on a seven-point scale ranging from 1 “not at all” to 7 “very much”: (i) “The same negative thoughts keep going through my mind again and again”, (ii) “Negative thoughts come to my mind without me wanting them to”, (iii) “I get stuck on certain negative thoughts and can’t move on” and (iv) “I feel weighed down by negative thoughts”. In a validation study, the $PTQ_{EMA}$ demonstrated excellent between-person reliability and average scores on the measure predicted depression, anxiety, and stress symptoms (Rosenkranz et al., 2020). In the current study, the $PTQ_{EMA}$ was incorporated into the app used by all trial participants (Newbold et al., 2020). Over a period of 10 days, participants received 5 beeps a day on their smartphones as prompts to complete the EMA questions. Intervals between the beeps varied randomly in length, however, participants could select a window of hours in which they wanted to receive the beeps throughout the day. The temporal difference between beeps within one day varied between 90 and 120 minutes.

**Procedure**

A detailed description of the procedure of the underlying trials including all assessed measures can be found in the study protocol (Newbold et al., 2020). In the following, we will focus on parts of the procedure relevant to the current research question. After having been screened for eligibility, all participants completed the baseline assessment including measures of trait rumination, trait worrying, depressive and anxiety symptoms as well as mental well-being. Consequently, participants were randomly allocated to either (i) use a self-monitoring app, (ii) to additionally receive generic cognitive-behavioral therapy self-help via app, or (iii) to additionally receive personalized emotional competence training self-help via app. Importantly, each condition included a self-monitoring option in the app. In each condition, participants were automatically enabled and instructed to download the app on their smartphone. The app was designed to be used for a period of three months. The 10-day EMA assessment took part from Day 5 to Day 14 of the app usage. One-, three- and twelve-months post-randomization, participants completed follow-up assessments comprising the same measures as the baseline assessment. Within our study sample with EMA data (N = 1,776), 941 participants completed the one-month follow-up, 880 completed the three-month follow-up and 800 completed the twelve-month follow-up.

**Data Analysis**

All analyses were conducted in R (R version 4.0.3; R Development Core Team, 2020).

### *Effects of Average Scores on the PTQEMA on the Outcomes*

We conducted linear regression analyses to investigate whether average scores of the $PTQ_{EMA}$ predicted sum scores on the PHQ-9, GAD-7 and WEMWBS at baseline and follow-ups. Average scores on the $PTQ_{EMA}$ measure were computed by calculating the mean sum score of the four EMA RNT items across all completed measurement time points for each participant. In each of the regression models, we controlled for sum scores on the trait RNT measures, i.e., the RRS-B and the PSWQ-A. In models predicting outcomes at follow-up, we additionally controlled for the baseline score on the respective outcome measure (i.e., PHQ-9, GAD-7 or WEMWBS, respectively) and the effects of trial condition. List-wise deletion was used to deal with missing data in the outcome variables.

### *Effects of RNT Dynamics on the Outcomes*

RNT inertia was calculated by computing autoregressive coefficients point according to Trull et al., 2015, indicating how well sum scores on the $PTQ_{EMA}$ at each time point are predicted by scores at the preceding time. RNT variability was calculated by computing the participant-specific standard deviation from the participant-specific mean sum score on the $PTQ_{EMA}$. Consequently, we conducted linear regression analyses to test whether inertia and variability predicted sum scores on the PHQ-9, GAD-7 and WEMWBS at baseline and follow-ups. We controlled for the same variables as in the models testing the effects of average scores on the PTQEMA and additionally controlled for the effects of average scores on the $PTQ_{EMA}$. RNT instability was calculated by computing the root mean square of successive differences (RMSSD) in sum scores on the $PTQ_{EMA}$ for each participant according to (Jahng et al., 2008). As for inertia and variability, we conducted linear regression analyses controlling for the same variables to test whether RNT instability predicted sum scores on the PHQ-9, GAD-7 and WEMWBS at baseline and follow-ups. Due to missing EMA data, RNT inertia and instability could only be calculated for a subset of 665 and 994 participants, respectively, leading to smaller samples for the models testing the effects of the dynamical parameters.

## Results

### Data Cleaning and Compliance

From Day 5 until Day 14 of their app usage, participants should have received 50 push-notifications (beeps) to answer the EMA questions. However, due to a fire in the server center and subsequent app outage for a month, participants received a varying number of beeps (e.g.,

the EMA phase started later than planned for some participants, EMA questions were sent either more or less often than planned). To maximize our sample size and analyze the EMA data despite these technical issues, we preprocessed the data in four steps. First, we split EMA data from an extended window (Day 1 until Day 60 of the app usage) into blocks where participants received consecutive beeps (less than two days difference between two beeps). Then, we filtered out blocks where participants received between 50 and 70 beeps as only a minority of participants ($n$ = 70) had blocks of exactly 50 consecutive beeps. In a third step, for participants with more than one block of 50 to 70 consecutive beeps, we filtered out the block with the highest answer rate. Finally, all participants who did not respond to the EMA assessment at all in the identified window were removed from the data set. All statistics reported in the paper pertain to the data set resulting from this data cleaning procedure. We additionally performed a sensitivity analysis on a subset of $N$ = 796 participants in which we only included EMA data from Day 5 until day 14 of the app usage (planned EMA period). Results from this sensitivity analysis did not substantially differ from the primary analysis regarding effects of average scores on the EMA-based RNT measure. However, results differed in terms of effects of the dynamic parameters, potentially due to decreased power in the complex models testing effects of (multiple) dynamic parameters in addition to testing the effects of average scores on the PTQEMA. The analytic code used for the sensitivity analysis can be found on OSF (https://osf.io/dm2ab/).

**Answer Rate EMA Assessment**

The mean answer rate for the EMA assessment was 26% ($SD$ = 26%).

**Correlations Between the PTQEMA and the Trait RNT Measures**

Table 2 shows means, standard deviations and Pearson correlation coefficients for the three RNT measures, RRS-B (sum score at baseline), PSWQ-A (sum score at baseline) and average sum scores on the $PTQ_{EMA}$. All correlations between RNT measures were significant. The correlation between RRS-B and PSWQ-A can be classified as large whereas the correlations between the two trait measures and the $PTQ_{EMA}$ can be classified as moderate (Cohen, 1988).

## Effects of average scores on the $PTQ_{EMA}$ measure on the outcomes

### *Depressive Symptoms*

Table 3 provides the results for the linear regressions testing the effects of the average score on the EMA-based RNT measure on depressive symptoms at baseline and at all three follow-ups. Average scores on the $PTQ_{EMA}$ significantly predicted sum scores on the PHQ at baseline when controlling for trait RNT measures (PSWQ-A and RRS-B sum scores at baseline). They also significantly predicted depressive symptoms at the three follow-up assessments when additionally controlling for baseline sum scores on the PHQ-9 and trial condition. Only the $PTQ_{EMA}$, but not the two trait RNT measures, significantly predicted depressive symptoms at the twelve-month follow-up.

### *Generalized Anxiety Symptoms*

Table 4 shows the results of the linear regressions predicting anxiety symptoms at baseline and at all three follow-up assessments. Average scores on the $PTQ_{EMA}$ significantly predicted sum scores on the GAD-7 at all four time points when controlling for the effects of the trait RNT measures and additionally controlling for the effects of trial condition and baselines scores on the GAD-7 in the models predicting symptoms at follow-up.

### *Well-Being*

Results of the linear regressions predicting well-being at baseline and at the three follow-up assessments are shown in Table 5. Average scores on the $PTQ_{EMA}$ showed significant negative associations with well-being at all four time points. At all three follow-up time points, the average score on the $PTQ_{EMA}$ but not the sum scores on the trait RNT measures significantly predicted sum scores on the WEMWBS when controlling for baseline scores on the WEMWBS.

## Effects of RNT fluctuation indices on the outcomes.

### *RNT Inertia and Variability*

RNT inertia during the EMA phase positively predicted depressive symptoms and negatively predicted well-being at the one-month follow-up. In addition, RNT variability predicted anxiety symptoms at the one-month- and three-month follow-ups. However, there were no other significant effects of RNT inertia and variability on the outcomes (see Supplementary Material, Table S1 – S3).

### *RNT Instability*

RNT instability predicted anxiety symptoms at the three-month follow-up and negatively predicted depressive symptoms at baseline). No other significant associations of RNT instability with the outcomes were found (see Supplementary Material, Table S4 - S6).

## Discussion

The current study aimed to investigate whether RNT measured in daily life via EMA predicts psychopathological symptoms and mental well-being. As hypothesized, average scores on the $PTQ_{EMA}$ significantly predicted higher depressive and generalized anxiety symptoms and lower mental well-being at baseline, one-month, three-months, and twelve-months follow-up. Notably, the average score on the $PTQ_{EMA}$ was a more consistent predictor of the mental health outcomes than scores on the trait RNT measures. For example, depressive symptoms at the twelve-month follow-up and mental well-being at all follow-ups were predicted by average RNT scores on the $PTQ_{EMA}$ , whereas trait RNT measures did not emerge as significant predictors. While several prior studies found that average scores on EMA RNT measures predicted psychopathological symptoms (Connolly & Alloy, 2017; Kornacka et al., 2021; Pasyugina et al., 2015; Rosenkranz et al., 2020; Timm et al., 2017), the present study is one of the first studies to show that this is still true when controlling for baseline symptoms and trait RNT measures.

When interpreting the results, it should be considered that $PTQ_{EMA}$ is process-focused and content-independent, whereas the trait RNT questionnaires we used are content-dependent (PSWQ-A measuring worrying about the future; Hopko et al., 2003; RRS-B assessing rumination about one's own negative mood; Treynor et al., 2003). Thus, one could argue that our findings may be based on a difference between process- vs. content-based measures, regardless of how they are administered. Reassuringly however, Rosenkranz, Müller, et al. (in preparation) used the $PTQ_{EMA}$ in a prospective study that additionally included the PTQ as a content-independent trait RNT measure. Results were similar to the findings of the present study, confirming that assessing content-independent process feature of RNT via EMA is indeed a promising method.

In addition to testing the predictive power of average scores on the $PTQ_{EMA}$ measure, we explored whether patterns in the temporal dynamics of RNT across the EMA phase were predictive of mental health outcomes. In sum, results were much less consistent than for average

scores on the $PTQ_{EMA}$. Yet, specific effects of certain RNT dynamics on some of the outcomes emerged. For example, high RNT inertia predicted higher depressive symptoms and lower well-being at one-month-follow up, whereas high RNT variability predicted higher generalized anxiety symptoms at one- and three-month follow-up. The findings regarding RNT inertia suggest that - in addition to how much individuals engage in RNT on average - an inert pattern of getting stuck in RNT might be linked to the development of depression and deterioration of overall mental well-being. In contrast, RNT inertia may be a less important dynamic in anxiety. Generalized anxiety symptoms rather seemed to be linked to high variability, that is individuals showing both relatively high and low RNT scores relative to their average RNT score. In line with this reasoning, high RNT instability, which can reflect low temporal dependency and/or a high amplitude of fluctuations in the repeatedly assessed RNT scores, predicted lower depressive symptoms at baseline and higher generalized anxiety symptoms at three-month follow-up.

Even though we found effects of these RNT dynamics, the findings should be interpreted with great caution as the analyses were exploratory and the associations did not emerge consistently across all measurement time points. The inconsistent findings are somewhat paralleled by EMA research on links between emotion dynamics and mental health, showing that low well-being and high psychopathological symptoms can be linked to high inertia (Brose et al., 2015; Houben et al., 2015; Koval et al., 2012; Koval et al., 2013; Kuppens et al., 2012), both high (Bos et al., 2019; Houben et al., 2015; Koval et al., 2013) and low variability (Rottenberg, 2005) and high instability (Houben et al., 2015; Schoevers et al., 2021) of affect. It has been argued that healthy emotional functioning might be characterized by flexible emotional changes (low inertia) within a moderate range (low variability/instability) (Houben et al., 2015). Similar reasoning could also be applied the process of RNT, suggesting that both rigidly engaging in RNT and getting stuck in negative thoughts over a longer period of time as well as engaging in RNT with substantially higher intensity than usual from time to time could be maladaptive and result in depression or anxiety, respectively. However, these ideas remain speculative at this stage and should be investigated more systematically in future research.

**Limitations**

We administered the $PTQ_{EMA}$ in a non-clinical sample of young adults who did not meet the criteria for a mental disorder at the beginning of the study. As a result, we only investigated

associations between scores on the $PTQ_{EMA}$ and subclinical symptoms. A next step for future studies could be to examine whether findings replicate when the measure is administered in a sample of patients with current diagnoses of or heightened risk for mental disorders. As RNT is considered to be a transdiagnostic factor, studies in samples including a broader spectrum of mental disorders beyond depression and anxiety disorder would be especially informative. A second limitation of the current study is that the response rate within the EMA assessment was low, with participants answering on average 26% of the EMA questions. There is a number of reason that potentially contributed to the low response rate. In the current study, EMA was administered as part of self-help apps for training emotional competencies and promoting mental health (Newbold et al., 2020). The usage of stand-alone self-help apps in general is characterized by low compliance and high rates of drop out (Fleming et al., 2018). Additionally, participants might have been more motivated to use other app contents instead of completing the EMA questions. Considering that our sample consisted of adolescents and young adults, an age group, where achieving good compliance with EMA is challenging (Wen et al., 2017; Wrzus & Neubauer, 2023), the relatively high sampling frequency (5 beeps per day) might have been too ambitious. Moreover, severe technical errors due to an outage in the server center during the EMA phase (see section Data cleaning and Compliance) likely influenced the response rate. The low response rate should be considered when interpreting the findings of the current study. The fact that average scores on the $PTQ_{EMA}$ predicted psychopathology even with this low response rate can be interpreted in favor of the robustness of this measure. At the same time, it is conceivable that the low response rate in our study may have reduced the predictive power of the indices for RNT dynamics. As the computation of both the inertia and the instability coefficient relies on consecutive data points, it is likely that these indices were affected by the substantial amount missing data. Relatedly, the low compliance rates in the current study prevented us from testing more sophisticated indices of RNT dynamics. Future studies should aim to more systematically disentangle different components of RNT dynamics, including short-term and long-term changes, as well as interactions between average levels of RNT and RNT inertia or variability. Finally, the study did not assess the cultural and geographic background of the participants, which limits conclusions about the generalizability of the findings.

**Conclusions and Outlook**

Our findings showed that measuring RNT in daily life using EMA provides additional value for the prediction of psychopathology and mental well-being in adolescents and young

adults. Importantly, average scores on the EMA measure predicted mental health outcomes more consistently than established trait RNT questionnaires. Thus, it appears promising to include EMA measures in studies investigating RNT, particularly when research is conducted in adolescent and young adult samples. Measuring RNT via EMA could for example be useful for assessing the effects of interventions that are designed to reduce RNT (Bell et al., 2022). In the current study we also investigated how different patterns in the temporal dynamics of RNT are related to mental health outcomes. However, as results were inconclusive, more research is needed to clarify how stable and dynamic features of RNT in daily life are linked to psychopathology. Further perusing this line of research may not only advance understanding of the mechanisms by which RNT leads to a deterioration of mental health but could also have implications for optimizing interventions. A recent study demonstrated that treatment outcomes can be predicted by certain dynamics in daily symptom profiles during psychotherapy (Olthof et al., 2023). Similarly, investigating dynamics of daily life RNT during treatments could have potential for improving the prediction of treatment responses and may ultimately facilitate personalization of treatments.

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**Table 1**

*Demographic variables*

| Variable | | Descriptive statistic |
|---|---|---|
| Age | | 18.87 (1.96) |
| Gender | female | 80.61% |
| | male | 18.28% |
| | both | 0.85% |
| | neither | 0.26% |
| Ethnicity | white | 85.20% |
| | mixed or multiple ethnicities | 5.38% |
| | Asian | 4.68% |
| | black | 1.70% |
| | Arab or middle eastern | 0.06% |
| | other ethnic group | 1.62% |
| | prefer not to say | 0.85% |
| Highest level of education | elementary or primary school | 2.64% |
| | lower secondary school | 31.38% |
| | upper secondary school or further education college | 56.63% |
| | higher education not at university (e.g., technical college) | 4.08% |
| | undergraduate degree | 5.02% |
| | postgraduate degree | 0.26% |
| Current occupation | students in secondary education | 24.49% |
| | students in university or higher education technical college | 41.24% |
| | working fulltime including caring for dependents (e.g., children) | 2.55% |
| | former students who left or completed secondary school and were not working or studying (yet) | 7.65% |
| | former student who left or completed university or higher education technical college and were not working (yet) | 2.47% |
| | prefer not to say | 21.20% |

*Note*. Mean (and standard deviation) is reported for age, percentages are reported for each level of the categorical variables.

**Table 2**

*Descriptive statistics and Pearson correlations for the RNT measures*

| | *Mean* | *SD* | $PTQ_{EMA}$(mean) | RRS-B | PSWQ-A |
|---|---|---|---|---|---|
| EMA RNT | 9.50 | 4.92 | 1 | .35 | .39 |
| RRS-B | 9.86 | 2.89 | .35 | 1 | .51 |
| PSWQ-A | 21.77 | 7.67 | .39 | .51 | 1 |

*Note*. *SD* = standard deviation; EMA RNT = Average sum score on the EMA RNT measure across all completed measurement timepoints; RRS-B = Sum score on the RRS-B at baseline; PSWQ-A = sum score on the PSWQ-A at baseline; correlations between all RNT measures were significant with $p < .001$.

**Table 3**

*Linear regressions predicting depressive symptoms (sum score on the PHQ – 9)*

| | Baseline | | | One-month Follow-up | | | Three-month Follow-up | | | Twelve-month Follow-up | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (*mean*) | 0.12 (0.09 – 0.16) | 0.17 | **<0.001** | 0.20 (0.15 – 0.25) | 0.24 | **<0.001** | 0.21 (0.15 – 0.27) | 0.23 | **<0.001** | 0.13 (0.06 – 0.20) | 0.13 | **<0.001** |
| RRS-B at baseline | 0.33 (0.26 – 0.40) | 0.26 | **<0.001** | 0.10 (0.02 – 0.19) | 0.07 | **0.022** | 0.15 (0.05 – 0.26) | 0.10 | **0.005** | 0.08 (-0.05 – 0.20) | 0.05 | 0.244 |
| PSWQ-A at baseline | 0.13 (0.10 – 0.16) | 0.28 | **<0.001** | 0.01 (-0.02 – 0.05) | 0.02 | 0.459 | -0.02 (-0.06 – 0.02) | -0.03 | 0.360 | 0.01 (-0.04 – 0.06) | 0.02 | 0.612 |
| PHQ-9 at baseline | | | | 0.44 (0.37 – 0.52) | 0.38 | **<0.001** | 0.42 (0.34 – 0.51) | 0.34 | **<0.001** | 0.38 (0.28 – 0.48 | 0.29 | **<0.001** |
| Condition (self-monitoring) | | | | 0.35 (-0.18 – 0.88) | 0.09 | 0.195 | 0.42 (-0.20 – 1.04) | 0.10 | 0.185 | 0.15 (-0.60 – 0.89) | 0.03 | 0.699 |
| Condition (self-monitoring + EC) | | | | 0.27 (-0.25 – 0.78) | 0.07 | 0.314 | 0.43 (-0.17 – 1.03) | 0.10 | 0.164 | 0.05 (-0.66 – 0.77) | 0.01 | 0.884 |
| Observations | 1176 | | | 941 | | | 880 | | | 800 | | |
| $R^2$ / $R^2$ adjusted | 0.316 / 0.314 | | | 0.325 / 0.320 | | | 0.263 / 0.258 | | | 0.157 / 0.151 | | |

*Note*. *B* (CI) = unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table 4**

*Linear regressions predicting generalized anxiety symptoms (sum score on the GAD – 7)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (*mean*) | 0.13 (0.10 – 0.17) | 0.17 | **<0.001** | 0.21 (0.16 – 0.25) | 0.25 | **<0.001** | 0.19 (0.14 – 0.25) | 0.22 | **<0.001** | 0.12 (0.05 – 0.18) | 0.13 | **<0.001** |
| RRS-B at baseline | 0.27 (0.20 – 0.34) | 0.20 | **<0.001** | 0.07 (-0.01 – 0.15) | 0.05 | 0.068 | 0.08 (-0.02 – 0.19) | 0.06 | 0.106 | 0.06 (-0.05 – 0.18) | 0.04 | 0.287 |
| PSWQ-A at baseline | 0.23 (0.20 – 0.25) | 0.46 | **<0.001** | 0.10 (0.06 – 0.13) | 0.19 | **<0.001** | 0.07 (0.02 – 0.11) | 0.12 | **0.002** | 0.05 (0.01 – 0.10) | 0.10 | **0.031** |
| GAD-7 at baseline | | | | 0.36 (0.29 – 0.42) | 0.34 | **<0.001** | 0.32 (0.24 – 0.41) | 0.28 | **<0.001** | 0.27 (0.17 – 0.37) | 0.24 | **<0.001** |
| Condition (self-monitoring) | | | | -0.14 (-0.60 – 0.33) | -0.03 | 0.572 | -0.05 (-0.65 – 0.55) | -0.01 | 0.879 | 0.04 (-0.64 – 0.71) | 0.01 | 0.919 |
| Condition (self-Monitoring + EC) | | | | -0.10 (-0.56 – 0.35) | -0.03 | 0.663 | 0.07 (-0.51 – 0.65) | 0.02 | 0.810 | 0.13 (-0.52 – 0.78) | 0.03 | 0.700 |
| Observations | 1176 | | | 942 | | | 886 | | | 800 | | |
| $R^2$ / $R^2$ adjusted | 0.462 / 0.461 | | | 0.445 / 0.441 | | | 0.279 / 0.275 | | | 0.171 / 0.165 | | |

*Note*. *B* (CI) = unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table 5**

*Linear regressions predicting mental well-being (sum score on the WEMWBS)*

| | Baseline | | | One-month Follow-up | | | Three-month Follow-up | | | Twelve-month Follow-up | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (*mean*) | -0.20 (-0.28 – -0.12) | -0.14 | **<0.001** | -0.23 (-0.31 – -0.14) | -0.14 | **<0.001** | -0.36 (-0.46 – -0.25) | -0.21 | **<0.001** | -0.20 (-0.32 – -0.08) | -0.12 | **0.001** |
| RRS-B at baseline | -0.53 (-0.68 – -0.39) | -0.22 | **<0.001** | -0.01 (-0.16 – 0.13) | -0.01 | 0.853 | -0.05 (-0.25 – 0.14) | -0.02 | 0.578 | -0.10 (-0.32 – 0.11) | -0.04 | 0.338 |
| PSWQ-A at baseline | -0.25 (-0.30 – -0.19) | -0.27 | **<0.001** | -0.01 (-0.07 – 0.05) | -0.01 | 0.682 | 0.03 (-0.04 – 0.10) | 0.03 | 0.390 | -0.02 (-0.10 – 0.07) | -0.02 | 0.673 |
| WEMWBS at baseline | | | | 0.63 (0.57 – 0.69) | 0.59 | **<0.001** | 0.50 (0.42 – 0.57) | 0.44 | **<0.001** | 0.39 (0.30 – 0.47) | 0.34 | **<0.001** |
| Condition (self-monitoring) | | | | -0.68 (-1.58 – 0.21) | -0.09 | 0.134 | 0.00 (-1.12 – 1.12) | 0.00 | 1.000 | -0.26 (-1.52 – 0.99) | -0.03 | 0.683 |
| Condition (self-Monitoring + EC) | | | | 0.32 (-0.55 – 1.19) | 0.04 | 0.475 | -0.23 (-1.31 – 0.86) | -0.03 | 0.682 | 0.01 (-1.20 – 1.21) | 0.00 | 0.988 |
| Observations | 1176 | | | 944 | | | 885 | | | 801 | | |
| $R^2$ / $R^2$ adjusted | 0.250 / 0.248 | | | 0.440 / 0.437 | | | 0.288 / 0.283 | | | 0.181 / 0.175 | | |

*Note*. *B* (CI) = unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

# 4. Study III:

*Heritability of Stable of Generalized Anxiety - a Longitudinal Twin Study in Young Adults*

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Funk, J., Morneau-Vaillancourt, G., Palaiologou, E., & Eley, T.C. (submitted for publication). Heritability of stable of Generalized Anxiety - a Longitudinal Twin Study in Young Adults

## Abstract

Despite the high prevalence and increasing rates of generalized anxiety among young adults, studies investigating factors that shape the course of these symptoms during the twenties are scarce. In addition, generalized anxiety can manifest in different ways, but it is unclear whether symptoms cluster under distinct dimensions in this age group. The current study addressed these gaps using data from the Twins Early Development Study (TEDS). First, we examined genetic and environmental contributions to continuity and change in generalized anxiety symptoms in young adulthood and the heritability of a latent factor reflecting stability over this period. Next, to explore potential dimensions of generalized anxiety, we investigated the factorial structure of symptoms as well as etiological influences underpinning the different factors. The sample comprised 6,429 twin pairs (10,836 individuals). Generalized anxiety was assessed at six waves from age 23 to 26 years. Genetic factors largely accounted for continuity and environmental factors for change in symptom severity scores. Furthermore, the heritability of stable generalized anxiety (60%) was substantially higher than that at any single time point (39 – 46%). Regarding the factorial structure of symptoms, we found evidence of two dimensions: worry-avoidance and somatic-distress symptoms. Genetic correlations ($rG$ = .77 - .91) between the two dimensions were higher than environmental correlations ($rE$ = .26 - .65), indicating that differences are more likely attributable to environmental effects. Most importantly, the current findings suggest that extracting temporal stability provides the strongest opportunity to identify genetic influences on generalized anxiety.

# Introduction

In recent years, rates of anxiety have risen dramatically among young adults (Archer et al., 2022; Eskander & Bhai, 2023; Goodwin et al., 2020; Slee et al., 2021). For instance, a representative survey from 2023 reported that 36% of young adults suffer from generalized anxiety symptoms such as excessive worrying about the future (Eskander & Bhai, 2023). Anxiety is highly disabling (Yang et al., 2021) and particularly when affecting young adults, is associated with poorer educational outcomes (Kasteenpohja et al., 2018) and huge costs for economy and society (Hendriks et al., 2015; McDaid & Park, 2022). Given the rising rates of anxiety in young adults as well as the associated burden, it is important to understand etiological factors underlying anxiety during the twenties.

## Temporal Stability of Anxiety

When investigating the etiology of anxiety, a key aspect to consider is temporal stability. Longitudinal studies show that anxiety symptoms fluctuate over time, both in individuals with and without diagnoses of anxiety disorders (Gustavson et al., 2018; Hovenkamp-Hermelink et al., 2019; Nes et al., 2007; Nivard et al., 2015; Struijs et al., 2020; Waszczuk et al., 2016). Notably, anxiety symptoms show more temporal fluctuation than other types of psychopathological symptoms (Leopold et al., 2016; Simonoff et al., 2020; Struijs et al., 2020). In addition, anxiety tends to fluctuate more in in children, adolescents and young adults than later in life (Bergen et al., 2007; Nivard et al., 2015; Petkus et al., 2016).However, despite fluctuations, longitudinal studies also show that there is considerable intra-individual stability in anxiety symptoms (Hovenkamp-Hermelink et al., 2019; Nes et al., 2007; Nivard et al., 2015; Prenoveau et al., 2011; Struijs et al., 2020; Waszczuk et al., 2016). As such, most people have a stable tendency reflecting how generally anxious they are.

Distinguishing between stable and time-varying anxiety is crucial as longitudinal twin studies suggest that they are underpinned by somewhat different etiological influences (Garcia et al., 2013; Nivard et al., 2015; Trzaskowski et al., 2012). Specifically, findings indicate that genetic factors largely account for continuity whereas environmental factors mostly explain change, with studies demonstrating this pattern in childhood (Trzaskowski et al., 2012), adolescence (Garcia et al., 2013; Waszczuk et al., 2016), young adulthood (Nes et al., 2007) as well as over the whole life course (Nivard et al., 2015).

Based on these consistent results, two other longitudinal twin studies in adolescents applied a method that allows to more precisely quantify genetic influences on the stable component of anxiety-like symptoms (Cheesman et al., 2018; Zavos et al., 2012). They extracted a latent stability factor from repeated measurements of anxiety sensitivity (Zavos et al., 2012) and emotional problems (Cheesman et al., 2018), respectively, and calculated the heritability of this latent stable factor, which was more heritable in both cases. For example, whilst genetic factors explained between 33 and 46% of variance in anxiety sensitivity at each of three waves, they explained 61% of variance in stable anxiety sensitivity (Zavos et al., 2012). Notably, extracting stability of emotional problems increased SNP-heritability in another study from 5 to 14% (Cheesman et al., 2018). However, despite rising rates of anxiety among young adults (Archer et al., 2022; Goodwin et al., 2020; Slee et al., 2021), no study to date has investigated genetic and environmental contributions to stable anxiety across young adulthood.

**Heterogeneity of Anxiety Symptoms**

Another feature of anxiety is that it can manifest in qualitatively different symptoms (Moriana et al., 2022; Tadi et al., 2022; Thompson et al., 2021). We recently showed that presentation of generalized anxiety symptoms was associated with age (Thompson et al., 2021). Specifically, younger people felt more irritable and anxious whereas older people described worrying more. Whilst some studies have examined potential dimensions of symptoms of generalized anxiety during young adulthood, their findings are inconsistent (Byrd-Bredbenner et al., 2020; Moreno et al., 2019). One found that a two-factor model best explained the structure of generalized anxiety with some items loading on a factor described as cognitive-affective and others on a factor labelled somatic (Moreno et al., 2019). In contrast, another study found support for a model where all items of a generalized anxiety measure loaded on a single factor (Byrd-Bredbenner et al., 2020). More research is needed to identify dimensions of generalized anxiety in young adulthood. In addition to investigating phenotypic dimensions, studies exploring how phenotypic heterogeneity is linked to differences in underlying genetic and environmental factors are crucial.

**Study Aims**

The current study had three aims. First, we investigated genetic and environmental contributions to continuity and change in generalized anxiety symptoms in young adulthood, from age 23 to 26 years. We predicted that genetic factors would substantially contribute to continuity and that environmental factors would largely explain change in generalized anxiety

symptoms. Second, given our hypothesis, we examined the heritability of stable generalized anxiety in young adulthood by extracting a latent stability factor across all waves. We predicted that heritability of stable generalized anxiety would be higher than heritability of generalized anxiety at any single time point. Third, we explored the factor structure of generalized anxiety in young adulthood in order to investigate potential symptom dimensions. Due to inconsistencies in the literature, we had no a-priori hypothesis regarding the factor structure. Following identification of dimensions, we tested the extent to which genetic and environmental factors explained their associations. Study aims and hypotheses were preregistered on the Open Science Framework platform (https://osf.io/6j7y5).

## Methods

### Sample

The current study used data from the Twins Early Development Study (TEDS; Lockhart et al., 2023), an ongoing longitudinal study following a cohort of twins born in England and Wales between 1994 to 1996. For the purpose of this study, we used data from the most recent six waves of assessment. Wave 2 to 5 took place during the Covid-19 pandemic. The sample for the analyses comprised 6,429 twin pairs, where at least one twin had data for at least one wave (10,836 individuals with data for at least one wave). Of this sample, 2199 twin pairs were monozygotic (MZ) and 4230 were dizygotic (DZ). Fifty-eight percent of the sample was female. Mean age (and standard deviation) was 22.85 (0.88) years at wave 1, 24.85 (0.85) years at wave 2, 25.02 (0.86) years at wave 3, 25.33 (0.86) years at wave 4, 25.73 (0.86) years at wave 5 and 26.38 (0.91) years at wave 6. Ethical approval for TEDS was granted by the King's College London Ethics Committee. Prior to each assessment wave, informed consent was collected.

### Measures

Generalized anxiety was assessed via the Generalized Anxiety Disorder assessment, 10-item version (GAD-10; Craske et al., 2013). The GAD-10 is a self-report measure of the severity of generalized anxiety symptoms. Respondents are asked to rate items such as "I have felt anxious, worried, or nervous" on a 5-point scale ranging from 0 "never" to 4 "all of the time". Total scale scores range from 0 to 40. The measure has demonstrated good psychometric properties (Lebeau et al., 2012) and usefulness in clinical settings (Craske et al., 2013). Internal consistency in the current study was high at all waves ($\alpha$ = .91 - .92).

**Statistical Analyses**

The current study used twin models to estimate genetic and environmental contributions to generalized anxiety. The twin design compares similarities between MZ twin pairs that share 100% of their genes and DZ twin pairs that share on average 50% of their genes. Based on differences in within-pair correlations across MZ and DZ twins, it is possible to estimate the influences of additive genetic effects (A), dominance genetic effects (D), shared environmental effects (C) and non-shared environmental effects (E) (Plomin et al., 2013). We estimated univariate twin models to assess the extent to which generalized anxiety at each of the six waves can be explained by genetic and environmental factors. We then conducted multivariate twin models to estimate genetic and environmental effects on generalized anxiety across waves. We first investigated genetic and environmental contributions to continuity and change in generalized anxiety using a Cholesky decomposition. In this model, contributions to continuity are quantified by estimating the extent to which genetic and environmental effects on symptoms at earlier waves influence symptoms at later waves. The Cholesky decomposition also estimates the magnitude of time-specific genetic and environmental effects (i.e., change). Second, to examine the heritability of stable generalized anxiety, we used a common pathway model. This model estimates the extent to which symptoms at each wave are explained by a latent stability factor and quantifies genetic and environmental influences on this latent stability factor and on the time-specific components. For univariate and multivariate twin analyses, we estimated ACE, ADE and AE models and interpreted the model with the best fit. We conducted all twin analyses using the R package "OpenMx" (Neale et al., 2016).

To investigate potential dimensions of generalized anxiety, we conducted factor analyses. At each wave, an exploratory factor analysis was performed in a randomly selected 70% subset of the data using the R package "psych" (Revelle, 2017). Subsequently, we conducted confirmatory factor analyses at each wave in the remaining 30% of the data to test the factor structure derived by the exploratory factor analyses using the r package "lavaan" (Rosseel, 2012). We then repeated the confirmatory factor analyses based on the whole sample at each wave to provide overview fit statistics. Evidence for dimensions was defined as follows. (1) Exploratory factor analyses showing a consistent factor structure with more than one factor across all waves and (2) confirmatory factor analyses demonstrating good model fit for this factor structure at all waves. In case of evidence for dimensions, we planned to rerun the univariate and multivariate twin models separately for the single dimensions. In addition, we

planned to analyze genetic and environmental contributions to overlap and specificity of dimensions by estimating a correlated-factor model.

# Results

## Phenotypic Correlations

Table 1 shows descriptive statistics for generalized anxiety scores at each of the six waves as well as longitudinal correlations. Mean scores were slightly higher for the waves that were conducted during the Covid-19 pandemic (wave 2 to 5). Generalized anxiety showed moderate to high temporal stability ($r$ = .56 - .76). Correlations were smaller, the higher the temporal distance between assessment waves.

## Univariate Twin Models

Due to skewness, GAD-10 total scale scores were square root transformed before twin analysis. The best fitting univariate twin models were an ADE model for generalized anxiety at wave 1 and AE models for generalized anxiety at wave 2 to 6. Fit statistics for all univariate twin models at each wave can be found in the Supplementary Information (Table S1). In the univariate models, variance explained by genetic factors ranged from 39% to 46% (see Supplementary Information, Table S2).

## Multivariate Twin Models

### *Cholesky Decomposition*

The best fitting Cholesky model was an AE model, see Table 2 for fit statistics and Figure 1 and Table 3 for the model and parameter estimates. As predicted, the model showed that genetic factors largely contributed to continuity in generalized anxiety from wave 1 to 6; The first set of genetic factors (A1) accounted for 39% of the variance at wave 1 and continued to account for a substantial part of variance at the later waves (34 – 38%). There also was some evidence of genetic innovation, mostly at wave 2, but even if significant, effects of later genetic factors were considerably smaller than effects of the first set of genetic factors. In line with our expectations, environmental effects were largely time-specific with time-specific environmental factors explaining between 31 and 61% of variance at each wave, but there was also some environmental continuity. For example, the first set of environmental factors (E1) continued to have significant effects on generalized anxiety at later waves (accounting for 7 – 9% of variance at wave 2 to 6).

### *Common Pathway Model*

The best fitting common pathway model was an AE model, see Table 2 for fit statistics and Figure 2 for the model with parameter estimates. The latent stability factor explained between 51% and 76% of the phenotypic variance in generalized anxiety at the single waves. Consistent with our expectations, genetic factors explained more variance in stable generalized anxiety (60%) than in generalized anxiety at any single time point (39% - 46%). In line with the results of the Cholesky decomposition, time-specific variance in generalized anxiety was largely explained by environmental factors (23% - 43%).

## Phenotypic Dimensions of Generalized Anxiety

Exploratory factor analyses at each wave consistently showed that a two-factor structure fit the data best (see Supplementary Information, Table S3). Factor loadings largely showed the same pattern for all waves (see Supplementary Information, Table S4). At five waves, six items loaded highest on a factor 1, which we labelled "somatic-distress" based on item content, and three items loaded highest on factor 2, which labelled "worry-avoidance". At wave 3, one additional item loaded highest on the worry-avoidance factor. To test the factor structure further, we performed confirmatory factor analyses at each wave . At each of the waves, model fit of the two-factor model with six items loading on the somatic-distress factor and three items loading on the worrying avoidance factor was good (see Supplementary Information, Table S5).

## Twin Models of Generalized Anxiety Dimensions

Univariate twin models showed that genetic factors accounted for 39 - 47% of variance in somatic-distress symptoms and for 29 - 37% of variance in worry-avoidance symptoms (see Supplementary Information, Table S6-7 and S10-11, for fit statistics and parameter estimates of the models). Cholesky decompositions yielded similar patterns as for generalized anxiety total scale scores with genetics largely accounting for continuity and environmental factors for change in both symptom subtypes (see Supplementary Information, Table S9 - S13). Common pathway models showed that heritability of stable somatic distress (55%) and heritability of stable worrying avoidance (62%) was substantially higher than heritability of these symptoms at the single time points (see Supplementary Information, Figure S1 and S2). Overall, heritability estimates for somatic-distress symptoms were slightly higher than for worrying avoidance symptoms, however, these differences are negligible as estimates for the two

dimensions were still within each other's confidence intervals. A correlated-factor model (see Supplementary Information, Table S14 and Figure S3) demonstrated that genetic correlations between somatic distress and worrying avoidance symptoms were high (.90 - .91 at the same time point and .77 -.85 cross time point). Environmental correlations between the symptom subtypes were lower than genetic correlations, but still in the moderate range (.62 - .65 at the same time point and .26 - .28 cross time point).

## Discussion

We found that genetic influences are the primary factor contributing to continuity in generalized anxiety in young adulthood. Furthermore, the heritability of a latent factor reflecting stability of generalized anxiety was substantially higher (60%) than heritability at any single time point (39 - 46%). In addition, although symptoms phenotypically clustered under a somatic-distress and a worry-avoidance dimension, underlying genetic influences were largely shared. In contrast, environmental factors showed more specificity to assessment time point and symptom dimension.

### Phenotypic Stability of Generalized Anxiety

Results indicated that despite fluctuations, generalized anxiety has a stable core in young adulthood. Interestingly, the latent stability factor explained more variance for the waves that were conducted during the Covid-19 pandemic (70 – 76%) than for the other two waves (51 - 63%). At the same time, mean generalized anxiety was higher for the waves that took place during the pandemic. These findings fit with evidence from a daily diary study in patients with Generalized Anxiety Disorder suggesting that higher rigidity of anxiety symptoms correlates with overall higher anxiety symptom severity (Fisher & Newman, 2016). Notably, the respective latent stability factor explained more variance in the somatic-distress (51 - 75%) than in the worry-avoidance dimension (39 - 64%), suggesting that the latter might be more susceptible to change. Consistent with this, accumulating evidence suggests that repetitive negative thinking such as worrying responds well to different psychological interventions (Bell et al., 2023; Monteregge et al., 2020). The finding that generalized anxiety has stable as well as dynamic components in young adulthood highlights the importance of considering persistent as well as time-specific etiological influences.

### Factors Underlying Continuity and Change of Generalized Anxiety from Wave to Wave

In line with prior studies (Garcia et al., 2013; Nes et al., 2007; Nivard et al., 2015; Trzaskowski et al., 2012; Waszczuk et al., 2016), genetic factors largely contributed to continuity in generalized anxiety across the study period. Specifically, the first set of genetic factors not only explained variance in generalized anxiety at age 21 but continued to substantially impact generalized anxiety into the mid-twenties. In addition, new genetic influences emerged at wave 2 (age ~25), the first wave conducted during the pandemic, and continued to have small, but significant effects on generalized anxiety at the later waves. No other new genetic effects were seen at any time point, thus genetic effects were somewhat less dynamic than in childhood and adolescence (Kendler et al., 2008; Waszczuk et al., 2016; Zavos et al., 2012). Similar to studies in other age groups, environmental effects were largely time-specific, indicating that environmental influences drive change in generalized anxiety during young adulthood. In contrast to studies in children and adolescents (Garcia et al., 2013; Kendler et al., 2008; Trzaskowski et al., 2012; Waszczuk et al., 2016), results furthermore indicated small but persistent environmental effects on generalized anxiety. These sustained environmental effects might contribute to the increased prevalence of generalized anxiety among young adults relative to other age groups (Eskander & Bhai, 2023). Environmental factors which increase the risk for persistently heightened levels of anxiety during young adulthood could for example be difficulties arising from the transition between education and employment (Klug et al., 2019).

### Factors Explaining the Stable Component of Generalized Anxiety

To better quantify stable effects on generalized anxiety in young adulthood we tested the extent to which variance in stable generalized anxiety was explained by genetic and environmental factors. In line with prior studies in adolescence (Cheesman et al., 2018; Zavos et al., 2012), the heritability of stable generalized anxiety was substantially higher (60%) than that for any single time point (39-46%). The increased heritability of stable relative to time-specific anxiety has important implications for genomic studies of anxiety. Genome-wide association studies have identified DNA variations associated with anxiety (Levey et al., 2020; Meier et al., 2019; Purves et al., 2020). But, as anxiety is only moderately heritable and highly polygenic, large sample sizes are required to detect associations (Smoller, 2020). Using a latent stable anxiety factor may help to overcome these challenges and provides a strong opportunity for identifying DNA variations contributing to the heritability of anxiety.

Our findings also have implications for studies of environmental influences on anxiety. Prior studies largely identified environmental influences as being time-specific (Garcia et al., 2013; Kendler et al., 2008; Nivard et al., 2015; Trzaskowski et al., 2012; Waszczuk et al., 2016). However, in the current study we found that environmental factors explained 40% of variance in stable generalized anxiety. Extracting stability likely increases the accuracy of the measure and thus potentially increases the power to detect all types of risk factors, whether genetic or environmental.

**Etiological overlap and specificity of generalized anxiety dimensions**

Generalized anxiety symptoms in young adults were also found to reflect two factors: somatic-distress and worry-avoidance. However, given that genetic influences on somatic-distress and worry-avoidance symptoms were largely shared, for genetic studies at least there is no need to examine these specific dimensions. In contrast, environmental influences were more specific to specific symptom dimensions. As such, when examining the effects of environmental risk factors on generalized anxiety (e.g., low socioeconomic status; Moffitt et al., 2007), it may be useful to utilize measures assessing these two dimensions.

**Limitations**

The current study has some limitations. First, whilst it is a strength having six waves, the design was limited by varying temporal distance between the waves. Specifically, the gap between the first and the second wave was relatively large (two years), whereas the time interval between the remaining waves was shorter (approximately three to six months). Therefore, it is unclear whether the evidence for genetic innovation at wave 2 is specific to age 25 or results from the temporal distance between the first and second wave. Secondly, we used the GAD-10 (Craske et al., 2013) for assessing generalized anxiety. A more commonly used measure of generalized anxiety is the Generalized Anxiety Disorder Questionnaire – 7 (GAD-7; Spitzer et al., 2006). Even though item content of the GAD-10 and GAD-7 is similar, small differences, e.g. in the number of items, limit comparability of the current findings with earlier studies. However, the greater length of this scale may have supported the identification of the two sub-scales, for which prior evidence using the GAD7 was mixed (Byrd-Bredbenner et al., 2020; Moreno et al., 2019). Finally, we only assessed generalized anxiety from early to mid-twenties. Our study revealed some differences to prior findings on the course of generalized anxiety in younger age groups, i.e., less dynamic genetic effects and more persistent environmental effects. However, in order to draw definitive conclusions about what drives the

rise of generalized anxiety in the twenties, future studies should assess generalized anxiety covering an extended period from the teenage years to early thirties.

**Conclusions**

The current findings suggest that extracting temporal stability of anxiety could substantially increase power for genomic studies of anxiety. In addition, we found that environmental factors have persistent effects on generalized anxiety in young adulthood, which has implications for investigating how environmental risks shape anxiety during this period. Exploring whether putative environmental risk factors have short- or long-term effects or differentially impact symptom dimensions could bring new insights into the etiology of generalized anxiety in young adulthood and ultimately inform treatment development.

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**Conflict of interest**

The authors have no conflict of interest to disclose.

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**Table 1**

*Descriptive statistics for generalized anxiety scores at each wave and longitudinal correlations with 95% confidence intervals*

| | age | *M* | *SD* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| 1. Generalized anxiety wave 1 | 22.85 | 7.35 | 7.46 | | | | | |
| 2. Generalized anxiety wave 2 | 24.85 | 8.63 | 7.52 | .57 (.55-.59) | | | | |
| 3. Generalized anxiety wave 3 | 25.02 | 8.82 | 7.71 | .59 (.56-.61) | .75 (.74-.77) | | | |
| 4. Generalized anxiety wave 4 | 25.33 | 9.26 | 7.95 | .57 (.54-.59) | .69 (.68-.71) | .73 (.71-.75) | | |
| 5. Generalized anxiety wave 5 | 25.73 | 8.81 | 7.65 | .57 (.55-.59) | .69 (.67-.71) | .72 (.70-.74) | .76 (.74-.77) | |
| 6. Generalized anxiety wave 6 | 26.38 | 7.77 | 7.35 | .56 (.54-.57) | .63 (.61-.65) | .66 (.64-.68) | .68 (.66-.69) | .71 (.69-.73) |

*Note.* Generalized anxiety wave 1 to 6 = raw total score on the Generalized Anxiety Disorder assessment, 10-item version, wave 1 to 6, age = mean age in years at each wave. Wave 2 to 5 took place during the Covid 19 pandemic.

**Table 2**

*Fit comparisons for multivariate twin models of generalized anxiety*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| Saturated | - | 97392.66 | 32794 | 97752.66 | N/A | N/A | N/A |
| Saturated | Constrained | 97539.09 | 32905 | 97677.09 | 146.44 | 111 | <.05 |
| *Cholesky Decomposition* | | | | | | | |
| Saturated | ACE | 97549.26 | 32905 | 97687.26 | 156.60 | 111 | <.01 |
| Saturated | AE | 97550.97 | 32926 | 97646.97 | 158.32 | 132 | .06 |
| Saturated | ADE | 97545.35 | 32905 | 97683.35 | 152.69 | 111 | <.01 |
| ACE | AE | 97550.97 | 32926 | 97646.97 | 1.71 | 21 | 1 |
| ADE | **AE** | **97550.97** | **32926** | **97646.97** | **5.62** | **21** | **1** |
| *Common pathway* | | | | | | | |
| Saturated | ACE | 97724.65 | 32942 | 97790.65 | 331.00 | 148 | <.001 |
| Saturated | AE | 97724.70 | 32949 | 97776.70 | 332.04 | 155 | <.001 |
| Saturated | ADE | 97721.67 | 32942 | 97787.67 | 329.01 | 148 | <.001 |
| ACE | AE | 97724.70 | 32949 | 97776.70 | 0.04 | 7 | 1 |
| ADE | **AE** | **97724.70** | **32949** | **97776.70** | **3.02** | **7** | **.88** |

*Note*. -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors; constrained = constrained model with equal means and variances across twins and zygosity groups as well as symmetric cross-twin cross-wave covariance matrices. The best fitting Cholesky and common pathway models are indicated in bold. Fit of the best fitting common pathway model was significantly worse than fit of the saturated model. However, this is common in twin studies with large sample sizes, where minimal variance deviations from the model's assumptions can be statistically significant (e.g., Waszczuk et al., 2016; Cheesman et al., 2018).

**Table 3**

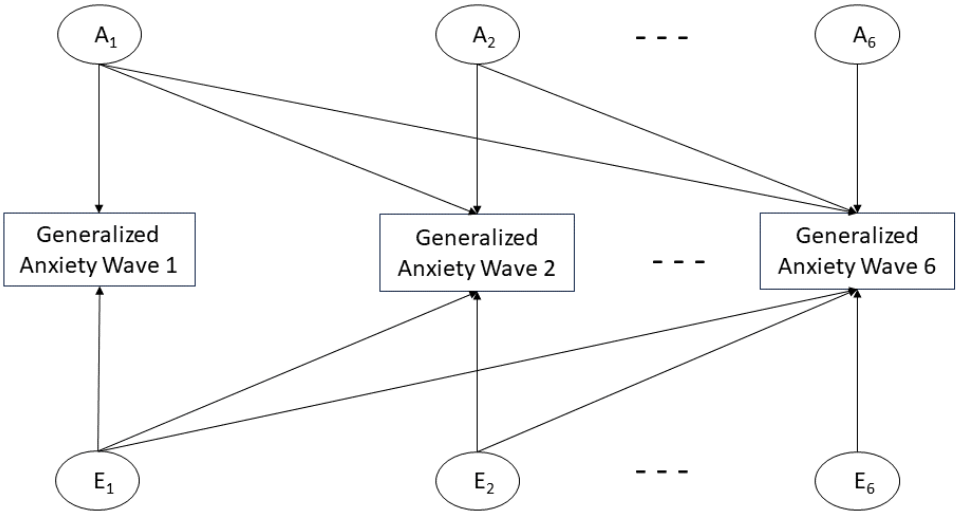
*Parameter estimates with 95% confidence intervals for the Cholesky decomposition of generalized anxiety*

| | Wave 1 factors | | Wave 2 factors | | Wave 3 factors | | Wave 4 factors | | Wave 5 factors | | Wave 6 factors | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $E_1$ | $A_2$ | $E_2$ | $A_3$ | $E_3$ | $A_4$ | $E_4$ | $A_5$ | $E_5$ | $A_6$ | $E_6$ |
| Generalized anxiety wave 1 | **.39** (.35-.43) | **.61** (.57-.56) | | | | | | | | | | |
| Generalized anxiety wave 2 | **.34** (.28-.39) | **.09** (.07-.11) | **.11** (.06-.15) | **.46** (.43-.51) | | | | | | | | |
| Generalized anxiety wave 3 | **.36** (.30-.41) | **.09** (.07-.12) | **.05** (.01-.09) | **.13** (.12-.17) | .01 (.00-.03) | **.36** (.33-.39) | | | | | | |
| Generalized anxiety wave 4 | **.38** (.32-.44) | **.08** (.06-.10) | **.04** (.01-.09) | **.10** (.07-.13) | .01 (.00-.06) | **.06** (.04-.07) | .02 (.00-.05) | **.32** (.29-.35) | | | | |
| Generalized anxiety wave 5 | **.36** (.30-.42) | **.08** (.06-.11) | **.07** (.03-.12) | **.07** (.05-.09) | .00 (.00-.05) | **.05** (.03-.07) | .02 (.00-.04) | **.04** (.02-.05) | .00 (.00-.03) | **.31** (.29-.34) | | |
| Generalized anxiety wave 6 | **.36** (.32-.41) | **.07** (.05-.09) | **.03** (.01-.07) | **.05** (.03-.07) | .00 (.00-.09) | **.03** (.02-.05) | .03 (.00-.09) | **.02** (.01-.03) | .00 (.00-.07) | **.02** (.01-.03) | .02 (.00-.06) | **.36** (.33-.39) |

*Note*. A = additive genetic factors; E = non-shared environmental factors; generalized anxiety wave 1 to 6 = square root transformed total score on the Generalized Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted. Significant estimates are indicated in bold

**Figure 1**

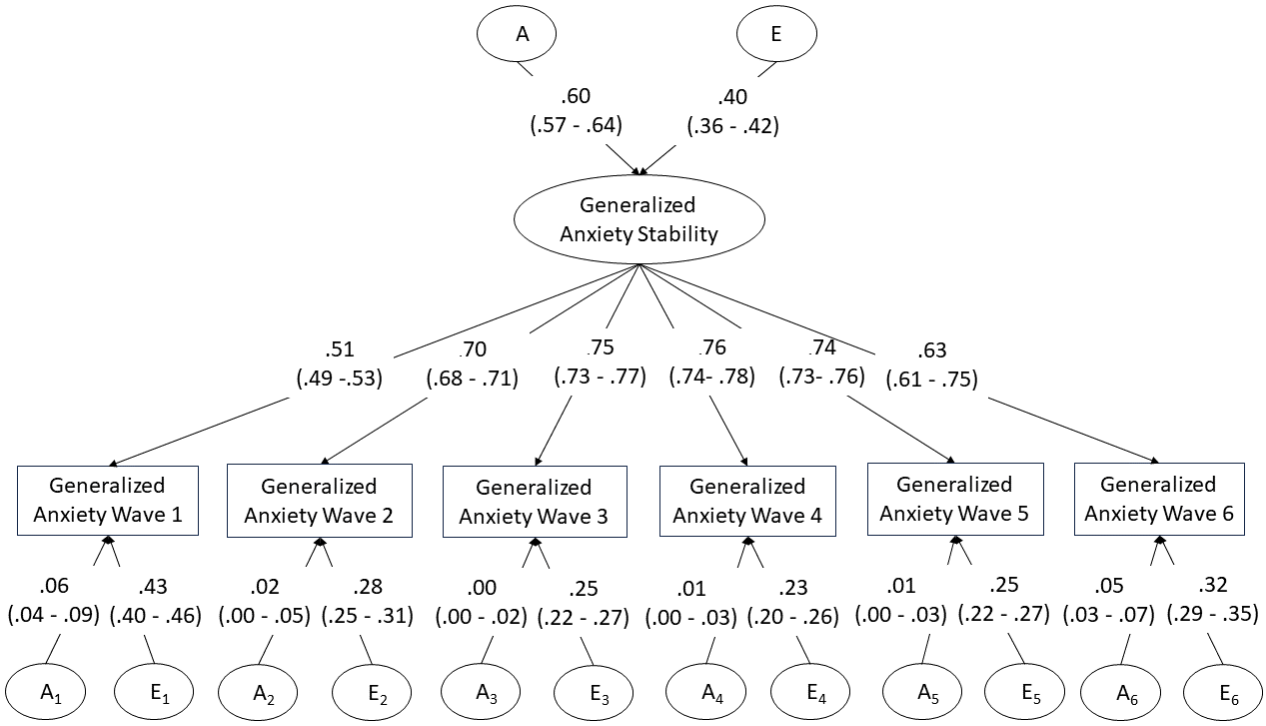
*Cholesky decomposition of generalized anxiety*




*Note*. A = additive genetic factors; E = non-shared environmental factors. The figure only includes three of the six waves, but the model was estimated based on six waves. Dashes represent wave 3 to 5.

**Figure 2**

*Common pathway model of generalized anxiety*




Note. A = additive genetic factors; E = non-shared environmental factors; generalized anxiety wave 1 to 6 = square root transformed total score on the Generalized Anxiety Disorder assessment, 10-item version, wave 1 to 6; generalized anxiety stability = latent stability of generalized anxiety. Parameter estimates presented in the figure are variance components. To obtain path coefficients, estimates should be square rooted

# 5. Study IV:

*Can an Intervention Designed to Reduce Repetitive Negative Thinking Alter the Response to a Psychosocial Stressor? A Randomized Controlled Study*

This chapter is a post-peer-review, pre-copyedit version of an article published in *Behaviour Research and Therapy.*

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## 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 initial increases in negative affect in response to the stressor did not differ between conditions, but that 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. 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.


**Keywords**: Repetitive negative thinking, digital interventions, stress response, emotional reactivity.

# Introduction

## 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 et al., 1983) or post-event processing after stressful social situations (Rachman et al., 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 et al., 2010; Arditte Hall et al., 2019; Arditte et al., 2016; Szabo et al., 2017; Watkins & Roberts, 2020). Additionally, a heightened tendency to engage in RNT was found to predict the development of future mental health problems (Funk et al., 2022; Spinhoven et al., 2018; Whisman et al., 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 et al., 2012; Schaich et al., 2013; White & Wild, 2016).

## 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 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 the effects of RNT on induced negative affect.

EMA studies have found reciprocal associations between RNT and negative affect (Blanke et al., 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 et al., 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 et al., 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 et al., 2018; Watkins et al., 2008) or measured before (Aldao et al., 2014) or after the stress exposure (Hilt et al., 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 et al., 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 et al., 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).

**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 et al., 2008; Watkins, 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 et al., 2019; Edge et al., 2021; Topper et al., 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 et al., 2020). Exploring how RNT-focused interventions affect processes such as emotional stress reactivity could provide information on how to further improve them.

### 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 pre-registration (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.

## Methods

### 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

[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).

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 .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 50$^{th}$ 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 et al., 2012) on the Patient Health Questionnaire-9 (PHQ-9; Spitzer et al., 1999). Furthermore, we had several exclusion criteria to minimize confounding effects due to factors that can be associated with HPA axis reactivity (Badrick et al., 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.

## Measures

### *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 et al., 2007) of the Ruminative Response Scale (RRS; Nolen-Hoeksema and 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 .81.

**Depressive Symptoms**. The German version (Löwe et al., 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 .64.

***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 et al., 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 .64 and .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 .83 for the primary appraisal scale and .77 for the secondary appraisal scale.

**State RNT**. A modified 4-item version (PTQ-S; Rosenkranz et al., 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., 2023; Rosenkranz et al., 2020). In the current study, Cronbach’s alpha was .86.

H**PA 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 one hour 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 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 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.

**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 minutes 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 to 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 48h hours to complete them. Furthermore, participants were sent 3 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.

### 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 (2 persons) and a video camera (duration: 15 minutes). 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 then started with a 5-minute anticipatory phase, in which participants could take notes for the upcoming task (3 minutes) and were told to fill out the PASA (2 minutes). 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 minutes). Finally, participants had to complete a mental arithmetic task (5 minutes), still while standing in front of the jury.

### Procedure

For an overview of the study timeline see Figure 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.

### 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 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 et al., 2005; Thomsen et al., 2005; Uhart et al., 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).

**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 minute 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 minutes relative to completing the TSST). Moreover, participants were instructed to fill out the PTQ-S 15 minutes after completing the TSST. In the periods between giving the samples and filling out the questionnaires, participants were not given any filler task 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.

**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.

***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.

***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 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 minute pre-stressor) was subtracted from the peak cortisol value (either measured at +10, +20 or +30 minutes 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 minutes post-stressor using a one-way analysis of covariance (ANCOVA) controlling for baseline cortisol values (-1 minute relative to stressor).

***Exploratory Analysis***

We explored whether participants in the intervention condition showed lower levels of state RNT (PTQ-S score) 15 minutes 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 doses.[2] All analyses were conducted in R (R Development Core Team, 2022) using the following packages: 'dplyr' (Wickham, François, et al., 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, et al., 2023) and 'ggpubr' (Kassambara, 2023a) for visualizing data, 'rstatix' (Kassambara, 2023b) for basic statistical tests, 'lme4' (Bates et al., 2023) and 'lmerTest' (Kuznetsova et al., 2020) for computing linear mixed-effects models, 'emmeans' (Lenth et al., 2019) and 'effsize' for calculating effect sizes for linear mixed-effects model (Torchiano & Torchiano, 2020) and 'sjPlot' (Lüdecke, 2023) for making results tables.

## Results

### 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.

### 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.

[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.

## Effect of the RNT-Focused Intervention on Subjective Stress Reactivity

### *Effect of the RNT-Focused Intervention on Negative Affect in Response to the TSST (Primary Hypotheses)*

Figure 2 depicts mean negative affect (sum score on the PANAS-NA) for each time point (-20,-1,+1,+10,+20,+30,+45 minutes 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 Figure 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 minutes post-TSST (see Figure 2). To further investigate this, we split the data into an initial response (-20,-1,+1 minutes relative to TSST) and a recovery phase (+10,+20,+30,+45 minutes 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 *d*s for the effect condition by time point based on estimated marginal means of the models, which suggested negligible to small effects of condition in the initial response phase ($d$ = 0.14 - 0.20) and small to moderate effects of condition in the recovery phase ($d$ = .31 -.53). Thus, even though effects were mostly small, participants in the intervention condition showed

[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).

significantly lower levels of negative affect throughout the recovery phase relative to participants in the control condition.

### *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.

### *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), $t(76.90) = -2.13$, $p = 0.04$, $d = 0.49$.

## Effect of the RNT-Focused Intervention on Biological Stress Reactivity

### *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),

[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.

$t(68.27) = -0.37$, $p = .71$, $d = 0.09$. In contrast to our predictions, a one-way ANCOVA controlling for baseline cortisol values (-1 minute pre-TSST) also did not show a significant effect of condition on cortisol level at the cortisol recovery time point (+45 minutes post-TSST), $F(1,67) = 0.410$, $p = .41$, $\eta_p^2 = .01$. 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).

### *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, $t(66.24) = -1.75$, $p = .08$, $d = 0.43$, (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).

### 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.

## 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

[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.

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 to 45 minutes 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.

**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 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).

**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.

### 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.

### 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.

**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.

# Declarations

## 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.

## Declaration of Competing Interest

The authors have no conflicts of interest to declare.

## Data Availability

Data and analytical code are available on OSF https://osf.io/bzrsh/resources. Note that for data protection reasons, variables containing information that could be traced back to natural persons, such as demographic variables, were removed from the data set.

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**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.

**Table 2**

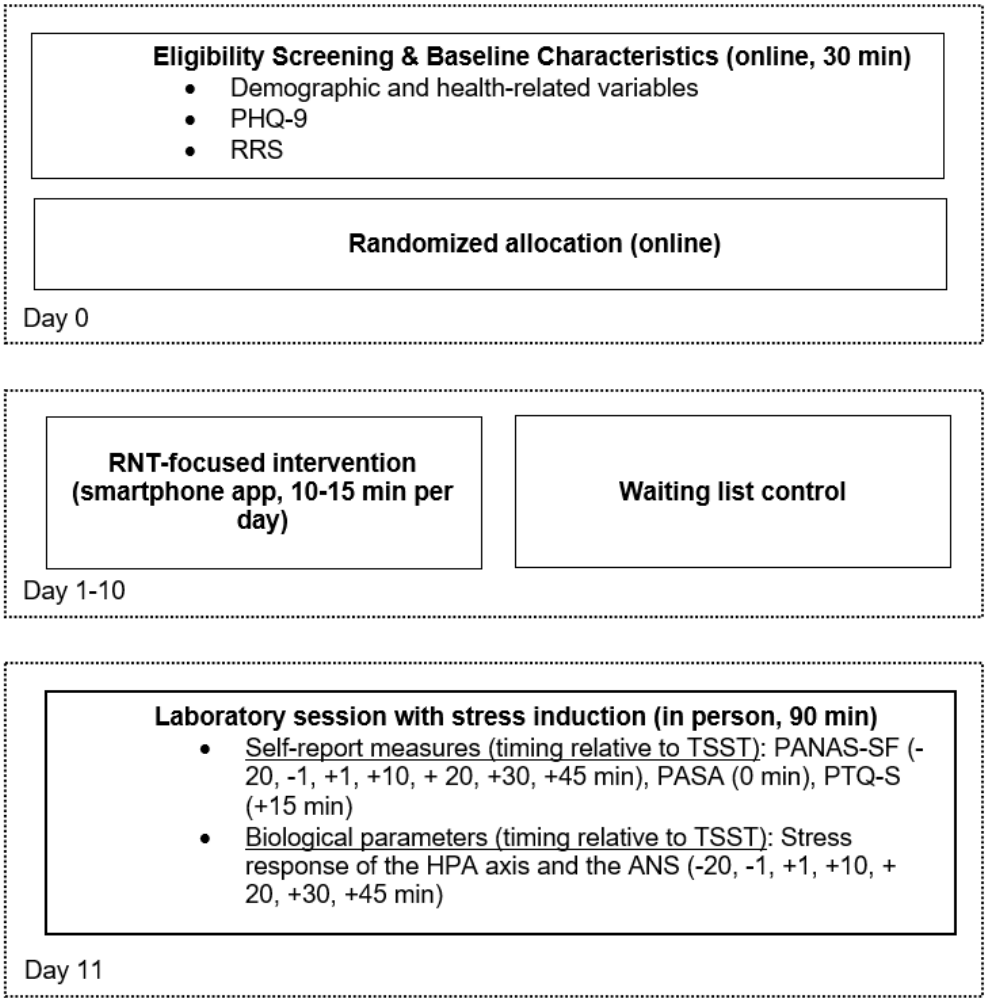
*Linear mixed-effects models predicting negative affect*

| | **PANAS-NA (all time points)** | | | | **PANAS-NA (initial response)** | | | | **PANAS-NA (recovery)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B*[95% *CI*] | *SE* | *β* | *p* | *B*[95% *CI*] | *SE* | *β* | *p* | *B*[95% *CI*] | *SE* | *β* | *p* |
| Time | -0.01 (-0.01 – -0.00) | 0.00 | -0.33 | **<.001** | 0.01 (0.00 – 0.02) | 0.00 | 0.22 | **.007** | -0.01 (-0.01 – -0.00) | 0.00 | -0.26 | **<.001** |
| Condition | 0.11 (0.01 – 0.22) | 0.05 | 0.16 | **.035** | 0.07 (-0.05 – 0.19) | 0.06 | 0.10 | .243 | 0.22 (0.08 – 0.36) | 0.07 | 0.34 | **.002** |
| Condition *Time | 0.00 (-0.00 – 0.00) | 0.00 | 0.05 | .241 | -0.00 (-0.01 – 0.01) | 0.00 | -0.10 | 0.906 | -0.00 (-0.00 – 0.00) | 0.00 | -0.10 | .181 |
| **Random Effects** | | | | | | | | | | | | |
| $\sigma^2$ | .07 | | | | .12 | | | | .03 | | | |
| $\tau_{00}$ | .04 | | | | .02 | | | | .06 | | | |
| *ICC* | .36 | | | | .13 | | | | .69 | | | |
| *N*, participants | 79 | | | | 79 | | | | 79 | | | |
| *N*, Observations | 553 | | | | 237 | | | | 316 | | | |
| Marg/ Cond $R^2$ | 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 minutes relative to stressor), PANAS-NA (initial response) = log-transformed sum score on the PANAS-NA (-20,-1,+1 minutes relative to stressor), PANAS-NA (recovery phase) = log-transformed sum score on the PANAS-NA (+10,+20,+30,+45 minutes relative to stressor), time = continuous variable, coded as the temporal distance relative to the stressor (range: -20 to +45 minutes), $\sigma^2$ = within-participant variability, $\tau_{00}$ = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marg/cond $R^2$ = Proportion of variance explained by fixed/ by fixed and random effects.

**Figure 1**

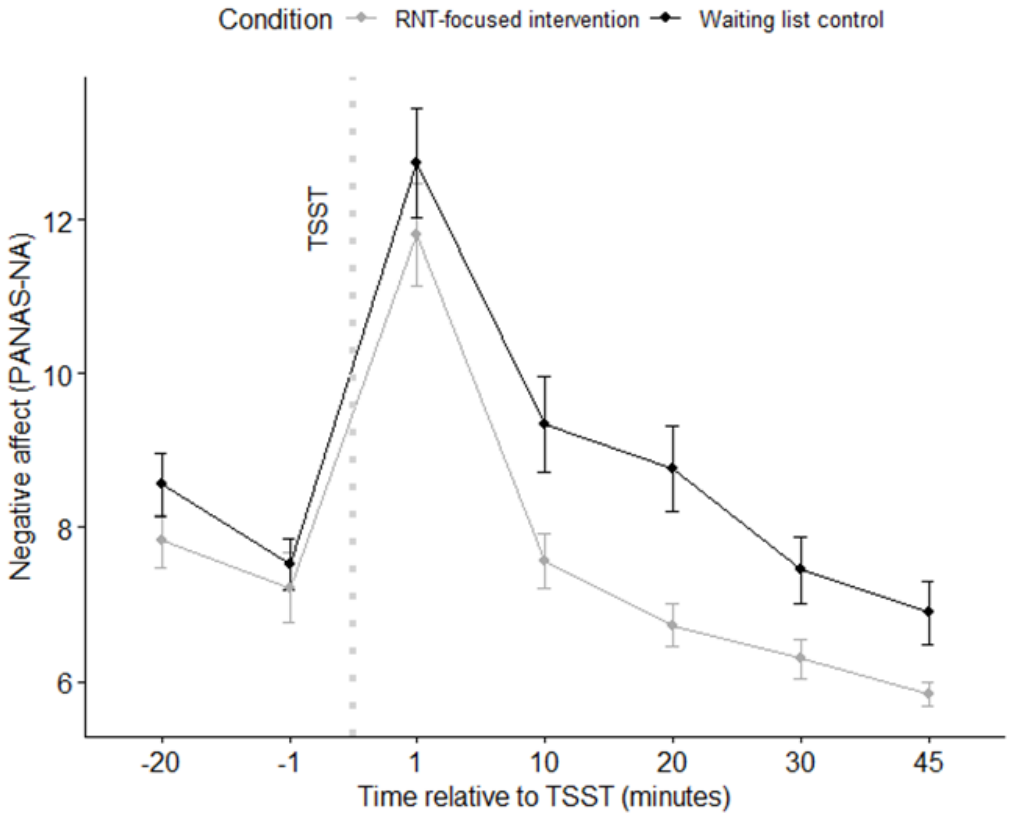
*Overview of the study procedure*




Note. 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.

**Figure 2**

*Mean negative affect with standard error bars by time (relative to the stressor) and condition*




*Note*. PANAS-NA = Sum score on the Negative Affect Subscale of the Positive and Negative Affect Schedule – Short-Form, TSST = Trier Social Stress Test.

# 6. Study V:

*An App Designed to Reduce Repetitive Negative Thinking can Decrease Depression and Anxiety in Young People Only when Used Frequently – Results from a Randomized Controlled Prevention Trial*

This chapter is a pre-peer-review, pre-copyedit version of an article submitted for publication at the *Journal of Behavior Therapy and Experimental Psychiatry*.

Funk, J., Kopf-Beck, J., Takano, K., Watkins, E., & Ehring, T.(submitted for publication). An App Designed to Reduce Repetitive Negative Thinking can Decrease Depression and Anxiety in Young People Only when Used Frequently – Results from a Randomized Controlled Prevention Trial

## Abstract

**Background and Objectives:** Rates of mental health disorders are rising among adolescents and young adults. Therefore, scalable methods for preventing psychopathology in these age groups are needed. As repetitive negative thinking (RNT) is a risk factor for depression and anxiety disorders, targeting RNT via smartphone app promises to be an effective, scalable strategy. The current three-arm, parallel group, randomized controlled trial tested whether a self-help app designed to reduce RNT decreased psychopathological symptoms and RNT in adolescents and young adults at risk for mental disorders.

**Method:** A sample of 16–22 years-olds with elevated levels of RNT ($N = 365$) were randomly allocated to either use a one of two self-help apps designed to reduce RNT for 6 weeks or to a waitlist. The full RNT-focused intervention app encompassed a variety of RNT-reducing strategies, whereas the concreteness training app focused on one of these strategies, namely, concrete thinking.

**Results:** The apps did not decrease depressive symptoms, anxiety symptoms and RNT relative to the waitlist. However, per-protocol analyses using a pre-defined minimum dose criterion showed that participants who used the full-RNT-focused intervention app more often, reported greater baseline to follow-up decreases in depressive symptoms, generalized anxiety symptoms, and worrying compared to waitlist.

**Limitations:** Include decreased power due to slightly more dropout than expected and limited generalizability due to the mostly female and highly educated sample.

**Conclusions:** Dose matters – RNT-focused prevention via a self-help app can only decrease depression and anxiety when the app is used with adequate frequency.


**Keywords:** Repetitive negative thinking, prevention, depression, anxiety, self-help apps

# 1 Introduction

The first onset of many mental disorders such as depression and anxiety disorders typically lies in adolescence or young adulthood (de Lijster et al., 2017; Kessler et al., 2007; Solmi et al., 2021). Additionally, rates of depression and anxiety among these age groups have risen dramatically in recent years (Archer et al., 2022; Goodwin et al., 2022; Goodwin et al., 2020; Slee et al., 2021). Conditions like depression and anxiety disorders are highly disabling (WHO, 2017; Yang et al., 2021) and can have a range of severe consequences – especially in young people, e.g., an increased risk for suicide attempts (Gili et al., 2019; Miche et al., 2018), poorer educational outcomes (Kasteenpohja et al., 2018) and high economic costs (Hendriks et al., 2015; McDaid & Park, 2022). As such, effective as well as scalable interventions for preventing and treating mental health problems in young people are urgently needed.

One possible avenue to meeting the increasing demand for mental health support among adolescents and young adults are interventions targeting known causal risk or maintenance factors for mental disorders, such as repetitive negative thinking (Topper et al., 2010). RNT refers to repetitive thinking about negative contents, which is experienced as intrusive and difficult to disengage from (Ehring & Watkins, 2008; Watkins, 2008). Commonly reported forms of RNT are rumination about one's own negative mood (Nolen-Hoeksema, 1991) and worrying about the future (Borkovec et al., 1983). A growing body of evidence, including longitudinal and experimental studies, suggests that RNT plays a key role in the development and maintenance of different mental disorders, such as depression and anxiety disorders (for an overview see e.g., Ehring & Watkins, 2008; Grierson et al., 2016; Watkins & Roberts, 2020). Importantly, research over the life course shows that levels of RNT increase throughout adolescence and reach their peak in young adulthood (Gonçalves & Byrne, 2013; Lilly et al., 2023; Sütterlin et al., 2012), indicating that targeting RNT might be particularly effective for addressing mental health problems in these age groups.

Several interventions, for example rumination-focused cognitive-behavioral therapy (RFCBT; Watkins, 2016), have been designed to reduce RNT. RFCBT thereby uses a variety of strategies, including identifying warning signs for RNT, repeated practice of helpful habits and training processing modes that are incompatible with RNT, e.g., being concrete and specific, problem-solving, mindfulness and self-compassion (Watkins, 2016). Findings from various trials in adolescents and adults with (a history of) depression have shown that RFCBT is efficacious in reducing RNT and depressive symptoms as well as in preventing relapse

(Hvenegaard et al., 2020; Jacobs et al., 2016; Langenecker et al., 2024; Watkins et al., 2011). Additionally, an adapted version of RFCBT has been found to prevent depression and Generalized Anxiety Disorder (GAD) in adolescents at risk for developing these conditions (Topper et al., 2017).

However, an important limitation of in-person delivered RNT-focused interventions is their low scalability. Therefore, recent trials tested whether RFCBT can still prevent depression and anxiety disorders in adolescents and young adults when delivered via a websites or smartphone apps in a (partly) automated manner. Topper and colleagues (2017) found that a guided web-based version of the intervention with personalized feedback by a therapist significantly reduced the 12-months prevalence of depression and GAD relative to a waitlist control group. Similarly, Cook et al. (2019) found significant effects of the same preventative intervention on the severity of depressive and anxiety symptoms and showed that especially individuals with high levels of stress at baseline benefited. Finally, a recent trial adapted RFCBT-based prevention to be delivered via a self-help smartphone app (Edge et al., in press). As the intervention was delivered in a mostly automated manner without contact to mental health care professionals, this format provides an even more scalable option. Results showed that the self-help app significantly reduced RNT as well as symptoms of depression and anxiety relative to a waitlist.

In sum, prior findings support the potential of RFCBT-based interventions as highly scalable preventative interventions for adolescents and young adults; yet evidence is still limited by a small number of studies. Further trials are needed to test the robustness of the findings. In addition, the effects of the single components of the intervention are yet to be established. There is evidence suggesting that training concrete thinking could be a particularly important active ingredient of the intervention (Guzey et al., 2021; Schaich et al., 2013; Watkins et al., 2008; Watkins et al., 2012; White & Wild, 2016). Hence, a leaner app intervention focused on concreteness training only could be an efficient way of preventing at-risk individuals from developing more severe problems; however, this has not been investigated empirically. Finally, accumulating research shows that dose is a crucial factor for the efficacy of scalable web- and app-based interventions. Importantly, usage rates of self-help apps designed to reduce mental health problems vary considerably (Lipschitz et al., 2022), whereby individuals with more frequent app use experience greater benefits (Crookston et al., 2017). Frequent engagement with the app contents might be particularly important for the effects of RNT-focused apps to unfold, given that excessive RNT is commonly conceptualized as a mental habit

that is rigidly triggered by various contexts (Watkins & Nolen-Hoeksema, 2014). According to this conceptualization, repeated practice is crucial for forming more helpful habits to replace habitual RNT. However, prior trials did not systemically investigate how intervention dose affects the efficacy RFCBT-based interventions when delivered via smartphone app.

### 1. 1 Study Aims

The primary aim of the current trial was to compare an RFCBT-based intervention via a self-help app to a waitlist control group in adolescents and young adults at risk for developing depression or anxiety disorders due to elevated levels of RNT. To explore active ingredients, two versions of the intervention were tested: the full RNT-focused intervention and concreteness training as a stand-alone intervention. As our sample comprised individuals scoring high on RNT at the beginning of the trial, we expected psychopathological symptoms to increase or remain constant in the waitlist control group. In contrast, we assumed that both interventions would have beneficial effects in that they would decrease sub-threshold psychopathological symptoms. Specifically, we investigated the following hypotheses. First, we predicted that both self-help apps would reduce depressive symptoms (primary outcome) relative to the waitlist control condition. Second, we hypothesized that both self-help apps would reduce scores on our secondary outcome measures for the risk factor RNT as well as generalized and social anxiety symptoms. As decreases in sub-threshold symptoms are precursors but no direct test of preventive effects, we additionally explored whether the interventions reduced the probability of meeting criteria for depression and anxiety disorders over the course of the study. Finally, we aimed to explore how intervention dose affected efficacy by comparing only those participants in the intervention conditions who fulfilled a pre-defined minimum dose criterion to the waitlist.

## 2 Material and Methods

### 2.1 Trial Design

This trial employed a superiority, three-arm parallel-group randomized controlled design, comparing two app interventions to a waitlist. Participants were allocated randomly (in a 1:1:1 ratio) to receive the full-RNT focused intervention via smartphone app, the concreteness training intervention via smartphone app or to wait for 18 weeks before being offered access to one of the apps. Full details on the trial design can be found in the trial protocol paper (Funk et

al., 2023) and the trial registration (German Clinical Trials Register: https://drks.de/search/de/trial/DRKS00027384).

### 2.2 Participants

To determine the required sample size, we conducted a power analysis based on the minimal clinically important difference (MICD) in depressive symptoms, d = 0.48 (Löwe et al., 2004). Using this medium effect size, the sample size required for a two-arm two-sided comparison at post-intervention was determined to be 93 participants per arm (90% power, alpha of .05). To account for 20% expected dropout at post-intervention, we aimed to recruit 351 participants (117 per trial arm). The sample size was estimated for a two-arm comparison (even though the study had three arms) as we did not have any a priori hypotheses regarding whether one of the apps would be more efficacious; therefore, hypotheses focused on two-arm comparisons only.

Details on recruitment and screening procedures are outlined in the trial protocol paper (Funk et al., 2023). Briefly, participants were recruited via social media, mailing lists, newsletters and at the campus of universities. The final sample comprised 365 16-22-year-olds with elevated levels of RNT, indexed either by scores $\geq 40$ on the Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991) or scores $\geq 50$ on the Penn State Worry Questionnaire (PSWQ; Borkovec et al., 1983). Since the trial was designed as a prevention and not a treatment trial, individuals meeting the criteria for major depression, GAD, and Social Anxiety Disorder (SAD) at the beginning of the trial were excluded from participation. Diagnoses were be determined by standard cut-offs on self-report measures, i.e., sum scores $> 9$ on the Patient Health Questionnaire-9 (PHQ-9; Spitzer et al., 1999), sum scores $> 9$ on the Generalized Anxiety Disorder-7 Questionnaire (GAD-7; Spitzer et al., 2006), and sum scores $> 35$ on the Social Interaction Anxiety Scale (SIAS; Heimberg et al., 1992). Moreover, participants receiving psychotherapy, not living in Germany, or not possessing a smartphone could not participate in the trial. As an incentive to participate, participants had the opportunity to take part in a lottery after they completed the study. In addition, participants studying psychology at LMU Munich could receive partial course credit.

## 2.3 Measures

### *2.3.1 Measures of RNT*

The **Ruminative Response Scale** (RRS; 22 items; Nolen-Hoeksema & Morrow, 1991; German version: Kuehner et al., 2007) was administered to assess depressive rumination (in the current study: $.74 \leq \alpha \leq .88$).

The **Penn State Worry Questionnaire** (PSWQ; 16 items; Meyer et al., 1990; German version: Stöber, 1995) was used to measure worrying (in the current study: $.84 \leq \alpha \leq .91$).

The **Perseverative Thinking Questionnaire** (PTQ; 15 items; Ehring et al., 2011) was used to assess participants' general tendency towards repetitive negative thinking focusing on process features of RNT, i.e., repetitiveness, intrusiveness and uncontrollability of thinking (in the current study: $.89 \leq \alpha \leq .93$).

### *2.3.2 Measures of Depressive and Anxiety Symptoms*

The **Inventory of Depressive Symptomatology** (IDS; 30 items; Rush et al., 1996; German version: Grässlin, 2004) was used as a measure of depressive symptoms (in the current study: $.79 \leq \alpha \leq .91$).

The **Generalized Anxiety Disorder Questionnaire-IV** (GADQ-IV; 10 items; Newman et al., 2002; German version: Hoyer, 2001) was used to measure the intensity of generalized anxiety symptoms (no Cronbach's α alpha can be calculated as measure has items with different response formats).

The **Social Phobia Inventory** (SPIN; 17 items; Connor et al., 2000; German version: Sosic et al., 2008) was used to assess social anxiety symptoms (in the current study: $.85 \leq \alpha \leq .92$).

### *2.3.3 Self-Report Measures of Clinical Diagnoses*

The **Patient Health Questionnaire** (PHQ-9; 9 items; Spitzer et al., 1999; German version: Löwe et al., 2002) was administered to make tentative diagnoses of depression (in the current study: $.35 \leq \alpha \leq .81$; note that the low internal consistency at baseline [.35] is not meaningful as variance of total scale scores at baseline was very limited due to the strict eligibility criteria).

The **Generalized Anxiety Disorder-7 Questionnaire** (GAD-7; 7 items; Spitzer et al., 2006; German version: Löwe et al., 2008) was administered to make tentative diagnoses of GAD (in the current study: $.44 \leq \alpha \leq .76$; for low internal consistency at baseline, see comment above on PHQ-9, which similarly applies here).

The **Social Interaction Anxiety Scale** (SIAS; 20 items; Heimberg et al., 1992; German version: Eidecker et al., 2020) was used to make tentative diagnoses of SAD (in the current study: $.79 \leq \alpha \leq .90$).

## 2.4 Interventions

An overview of the self-help app is provided in Table 1 (for full details see the trial protocol paper; Funk et al., 2023).

### *2.4.1 Full RNT-Focused Intervention*

The full RNT-focused intervention employed core principles of RFCBT (Watkins, 2016). A similar app intervention based on RFCBT has been evaluated as part of another recent prevention trial (Edge et al., in press). The app comprised several modules: psychoeducation on RNT and strategies to reduce RNT, identifying personal triggers of RNT and stress, concreteness training, engaging in opposite actions, relaxation/mindfulness-based exercises, self-compassion, setting priorities to cope with stress-related worries, tracking current emotions and repetitive thoughts, and making specific if–then-plans to apply the acquired strategies in every-day life. These contents were embedded within the following structure. The knowledge section comprised psychoeducation on RNT and different strategies to reduce RNT. The challenges section contained exercises to compare different less helpful versus more helpful (i.e., RNT-reducing) styles of reacting to difficult situations, for example abstract vs. concrete thinking or kind vs. unkind self-talk. The tools section consisted of exercises to facilitate transfer of the different helpful, RNT-reducing strategies to everyday life. The mood tracker section allowed participants tracking current emotions and repetitive thoughts in daily life. In the if–then-plans section, participants could make specific plans to use the acquired strategies in their daily lives.

The intervention was unguided, meaning that over a period of 6 weeks participants could freely choose activities from the different sections of the app and adjust the intervention to their current needs. However, participants were instructed to use the app as consistently as possible and received push-notifications (three to four per week) encouraging them to complete certain

exercises (i.e., challenges or tools) in the app. The app logged every completed challenge, tool, or if-then-plan. To increase usability, the app combined animations, videos, audio exercises, explanatory texts, and multiple choice, and open-question formats. The intervention was run on the m-Path app (m-Path, 2021).

### *2.4.2 Concreteness Training Intervention*

Instead of providing several strategies to reduce RNT, the concreteness training app exclusively focused on exercises designed to promote concrete thinking. Hence, the number of challenges and tools available was smaller than in the full-RNT-focused app and participants received less push-notifications to complete exercises in the app. This reduced set-up was adopted based on the goal to test concreteness training as a more time-efficient alternative to the full RNT-focused intervention.

## 2.5 Procedure

An overview of the procedure is presented in a CONSORT flow diagram (Schulz et al., 2010) in Figure 1. Following the the eligibility screening, participants completed the pre-intervention assessment. Eligibility screening and pre-intervention assessment comprised the following baseline measures: PHQ-9, GAD-7, and SIAS as self-report measures for making tentative diagnoses, IDS, GADQ, and SPIN for assessing the intensity of depressive, generalized anxiety, and social anxiety symptoms, and RRS, PSWQ, and PTQ as measures of RNT. After having completed the eligibility screening and pre-intervention assessment, participants were randomly assigned to either the full RNT-focused intervention, the concreteness training intervention, or the waitlist control condition. Randomization was conducted independently using pre-generated computerized allocations based on blocking with variable block sizes to balance sample sizes across trial conditions (Efird, 2011). The randomization table providing the basis for allocation was created by an independent statistician who was not part of the study team. Allocation concealment was ensured, as the allocation code was not visible for the study team before a participant had been assigned to one of the trial conditions. Enrolment and the generation of the allocation code were fully automatized and thus could not be influenced by the study team monitoring data collection. Due to known gender differences in depressive symptoms and RNT (Johnson & Whisman, 2013; Nolen-Hoeksema & Hilt, 2009), randomization was stratified according to gender (male, female, non-binary). After randomization, participants in both intervention conditions were instructed to download the intervention app and use them for 6 weeks. Participants in the waitlist condition were

instructed to wait until the post-intervention assessment. At post-intervention and follow-up (6 and 18 weeks after pre-intervention), participants again completed the questionnaires that had been administered at baseline. After the follow-up assessment, participants in the waitlist condition were offered the option to use one of the two intervention apps of their choice. Eligibility screening, pre-intervention, post-intervention, and follow-up assessment were conducted online using the Research Electronic Data Capture platform (REDCap; Harris et al., 2009). Participants provided informed consent before taking part in the study. All procedures were approved by the ethics committee at the Department of Psychology, LMU Munich (2021_57_Funk_c).

### 2.6 Statistical Analyses

A detailed statistical analysis plan can be found in the trial protocol (Funk et al., 2023) and the trial registration (https://drks.de/search/de/trial/DRKS00027384). All analyses were conducted in R (R Development Core Team, 2022). Anonymized data set, code book, and analytic code are available publicly ( https://drks.de/search/de/trial/DRKS00027384).

#### *2.6.1 Effects at Post-Intervention*

We investigated whether the two apps reduced depressive symptoms relative to the control condition using a linear mixed-effects model with random effects for participants (primary analysis). In the model, the effects of condition (full RNT-focused intervention, concreteness training intervention, waitlist control condition), time (baseline, post-intervention), and condition*time interaction were tested. To further investigate significant interaction effects, we planned to use simple slope tests. The primary analysis was repeated for the secondary outcomes RNT, generalized anxiety symptoms, and social anxiety symptoms, respectively. In addition, we conducted logistic regression analyses to explore whether the interventions decreased the probability of fulfilling the criteria for a depressive episode, GAD, and SAD at post-intervention. Analyses were intention-to-treat (ITT) analyses and missing data was handled via full-information maximum likelihood (FIML) in the linear mixed effect-models in the primary and secondary analyses. Logistic regressions were complete cases analyses using only data from participants who completed the post-intervention assessment.

#### *2.6.2 Effects at Follow-Up*

Analyses of effects at post-intervention were adapted to investigate whether the predicted effects extended to the follow-up timepoint.

### *2.6.3 Minimum Dose Sensitivity Analyses*

In addition to the ITT analyses, we performed sensitivity analyses to explore whether differences between conditions were influenced by the intervention dose. Specifically, we repeated all analyses comparing only those participants in the intervention conditions who fulfilled a pre-defined minimum dose criterion to participants in the waitlist control condition (see statistical analysis plan, https://drks.de/search/de/trial/DRKS00027384). The minimum dose criterion was based on the rationale that active ingredients were learning new concepts and practicing new skills and operationalized as follows: (a) Psychoeducation and learning new skills/mindsets through practice of Challenges alone (at least 2 Challenges completed) OR (b) Practicing alternative responses to increase the likelihood of forming new habits through repeated use of Tools alone (at least 4 completed), OR (c) A combination of learning new skills/mindsets AND taking actions to transfer them to everyday life (completion of at least 1 Challenge AND 2 tools OR if-then-plans).

## 3 Results

### 3.1 Baseline Differences Between Conditions

Table 2 shows descriptive statistics of baseline variables by condition before randomization. In one-way ANOVAs and chi-squared tests, conditions did not differ on any of these variables at baseline, confirming that the randomization was successful.

### 3.2 Dropout and Missing Data

As shown in Figure 1, 68.22% of the total sample (249 participants) completed the post-intervention assessment and 47.67% of the total sample (174 participants) took part in the follow-up assessment. In addition to missing data at post-intervention or follow-up, four participants had missing data on the IDS at baseline, and two participants did not respond to the demographic item concerning education.

### 3.3 Intervention Dose

On average, participants in the intervention conditions completed M = 3.25 tools or challenges (SD = 5.32) and registered M = 0.42 if-then-plans (SD = 1.10) in the app. Mean completion of tools and challenges was significantly higher in the full RNT focused intervention (M = 4.27; SD = 6.06) than in the concreteness training intervention condition (M = 2.22; SD = 4.24), $t(216.6) = -3.05$, $p > .01$, $d = 0.39$. In contrast, the mean number of if-than-

plans did not differ significantly between conditions, t(232.7) = 0.14, p = 0.88, d = -0.02. In sum, 46.91% of participants in the intervention conditions (114 participants, 59 in the full RNT-focused intervention and 55 in the concreteness training intervention) fulfilled the minimum-dose criterion.

### 3.4 Effects at Post-Intervention

A linear mixed-effects model did not show significant condition*time interactions. Hence, contrary to our primary hypotheses the two interventions did not significantly reduce depressive symptoms from pre- to post-intervention relative to the control condition (see Table 3 for descriptives, Table 4 for the model and Table 5 for effect sizes). Similarly, linear mixed-effect models did not support our secondary hypotheses regarding effects of the intervention on generalized anxiety symptoms, social anxiety symptoms, rumination, worrying, and content-independent RNT (see Table 3, Tables 4 and 5 for details). In logistic regression analyses, the interventions did not significantly decrease probabilities of meeting the criteria for diagnoses of depression, GAD, and SAD at post-intervention relative to the waitlist condition (see Supplementary Material, Table S1).

### 3.5 Effects at Follow-Up

Effects at follow-up were consistent with the non-significant results at post-intervention. Linear mixed-effects models did not provide evidence that change in depressive symptoms, generalized anxiety symptoms, social anxiety symptoms, and RNT from baseline to follow-up differed significantly between conditions (see Supplementary Material, Table S2 and S3). Likewise, logistic regressions did not find indications for decreased probabilities of meeting the diagnostic criteria for depression, GAD, and SAD at follow-up in the intervention conditions (see Supplementary Material, Table S4).

### 3.6 Minimum Dose Sensitivity Analyses

Results of the minimum dose analyses did not differ from the ITT analyses with regards to effects at post-intervention (see Supplementary Material, Table S6, S67, and S8). However, linear mixed-effects models testing effects at follow-up revealed significant condition*time interactions for depressive symptoms, generalized anxiety symptoms, and worrying (see Supplementary Material Table S9, S10, and S11). Specifically, the models indicated larger baseline to follow-up decreases in all three variables in the full RNT-focused intervention relative to the waitlist control condition. The significant effects are supported by substantially

larger effect sizes for baseline to follow-up decreases in the full RNT-focused intervention condition for these outcomes (Cohen's d = .36 to .44) compared with the other two conditions (Cohen's d mostly <.20), see Supplementary Material, Table S10. Differences between ITT and minimum dose analyses are illustrated in Figure 2, which depicts the course of depressive symptoms over the trial by condition for the ITT and the minimum does sample. While these results are promising, it is important to note that when applying Holm's procedure to correct for multiple outcomes only the condition*time interaction for depressive symptoms remained significant. In addition, logistic regressions did not show significantly decreased probabilities for diagnoses of depression, GAD, and SAD at follow-up in the minimum dose analyses (see Supplementary Material, Table S12).

## 4 Discussion

Contrary to our expectations, the ITT analyses showed that self-help apps designed to reduce RNT did not decrease depressive symptoms, social anxiety symptoms, generalized anxiety symptoms, and RNT relative to the waitlist control condition. Likewise, the apps did not decrease probabilities for diagnoses of depression, GAD, and SAD as indexed by cut-offs on self-report questionnaires at post-intervention or follow-up. However, there were indications that the more extensive full RNT-focused intervention had beneficial effects when participants used the app with adequate frequency. Specifically, participants in the full RNT-focused intervention condition who fulfilled a pre-defined minimum dose criterion reported greater decreases in depressive symptoms, generalized anxiety symptoms, and worrying from baseline to follow-up compared to the waitlist.

Findings from the ITT analyses stand in contrast to prior studies where web- or app-based RNT-focused interventions significantly decreased symptoms of depression, generalized anxiety as well as levels of RNT in adolescents and young adults (Cook et al., 2019; Edge et al., in press; Topper et al., 2017). In addition, RFCBT has consistently proven to be efficacious when delivered in an in-person setting (Hvenegaard et al., 2020; Jacobs et al., 2016; Langenecker et al., 2024; Topper et al., 2017; Watkins et al., 2011). Therefore, the current ITT null findings may largely be due to how the interventions were delivered. An important difference to two earlier trials testing scalable online interventions based on RFCBT is that the intervention in the current study was delivered as an unguided self-help app. In contrast, prior studies tested guided web-based versions of the intervention with personalized feedback by clinicians (Cook et al., 2019; Topper et al., 2017). Our unguided apps might have failed to

sufficiently motivate participants to practice strategies for reducing RNT. In line with this notion, the mean intervention dose was considerably lower than in the two prior trials testing guided web-based versions of the intervention (Cook et al., 2019; Topper et al., 2017). On a theoretical level, it is highly plausible that repeated practice is necessary for reducing RNT. Excessive RNT is commonly conceptualized a mental habit that is automatically and rigidly triggered by various setting and circumstances (Watkins & Nolen-Hoeksema, 2014). Therefore, intervention dose should be a key factor determining whether individuals can break habitual RNT.

Further supporting the importance of an adequate dose for the efficacy of app-based RNT-focused interventions, our minimum dose analyses suggested that participants who used the full RNT-focused intervention app more showed significant improvements at follow-up. Notably, effects took until the follow-up time point to unfold. Nevertheless, our findings indicate that in order to design effective, scalable RNT-focused app interventions it is crucial to find ways for increasing usage rates.

There is a certain trade-off between increasing scalability and making app interventions as engaging as possible. For example, personalized feedback by clinicians likely has positive effects on usage rates, but also makes interventions less scalable compared to unguided self-help app interventions. However, two recent studies have given indications for how to increase usage rates and efficacy without compromising scalability. Edge et al. (in press) tested a similar unguided RNT-focused app as the current trial, but additionally included a feature to monitor mood and RNT in daily life, sending several reminders per day to complete these ratings. Results showed beneficial effects of the app relative to a waitlist condition. In addition, in another recent study we found that when we delivered the contents of the current full RNT-focused intervention in an unguided but more structured format, usage rates were substantially higher (Funk et al., 2024). Thus, a clear structure with new contents in the app each day and a feature to consistently track mood and RNT throughout the intervention might increase usage of RNT focused self-help apps and augment their positive effects on mental health.

Considering that the format, in which the app interventions were delivered, might not have been ideal to realize their full potential, the non-superiority of the concreteness training only self-help app over the waitlist in all analyses does not provide conclusive evidence. In fact, the overall more promising results in the full RNT-focused intervention condition might be a results of even lower usage rates and less participants fulfilling the minimum dose criterium in

the concreteness training condition. In contrast to the current study, a prior trial in patients with depression showed that guided concreteness training significantly reduced depressive symptoms and RNT relative to treatment as usual (Watkins et al., 2012). Therefore, it appears promising to further investigate potential active ingredients of more extensive RNT-focused interventions, e.g. concreteness training, under optimized conditions for engagement with the intervention.

### 4.1 Limitations

One limitation of the current trial is that statistical power for detecting effects of the interventions might have been too low. While we recruited slightly more participants than our estimated target sample size, dropout was higher than expected (30% instead of 20% at post-intervention) leaving a somewhat smaller sample than we had aimed for. Moreover, the current trial is limited by the fact that diagnostic status was indexed via standard cutoffs on self-report measures and not assessed in structured clinical interviews. Future research investigating RNT-focused self-apps for the prevention of mental disorders should additionally use clinical interviews to get more valid estimates of their effects on incidence of mental disorders. Finally, the study sample mostly consisted of female university students. This was expected given that our eligibility criteria included frequently engaging in RNT, which is more common in females (Johnson & Whisman, 2013). Notwithstanding, future studies should aim to recruit more diverse samples to investigate whether effects of RNT-focused self-help apps are dependent on factors like gender.

### 4.2 Conclusions

Prior research suggests that targeting RNT via a self-help app could be a promising scalable strategy for the prevention of psychopathology in at-risk adolescents and young adults. However, the current trial indicates that when adapting established RNT-focused interventions to be delivered in highly scalable unguided self-help app formats, there is a risk that they do not realize their full potential due to too low usage rates. For scalable RNT-focused interventions to be effective, it therefore seems crucial to deliver them in formats that encourage frequent engagement with the intervention content provided.

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**Table 1**

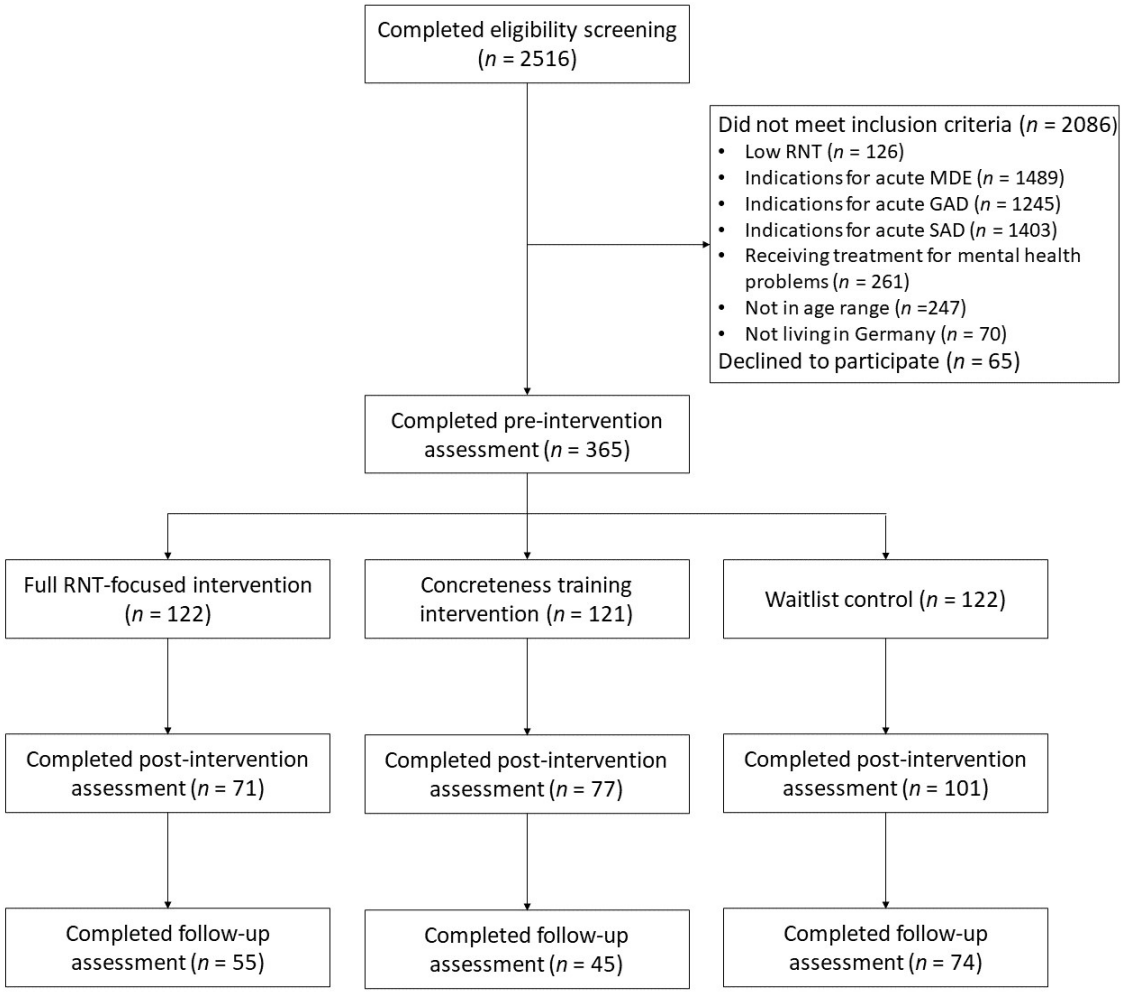
*Modules and Key Elements of the App-Based Interventions*

| **Full RNT-Focused Intervention** | | **Concreteness Training Intervention** | |
|---|---|---|---|
| Module | Key elements | Module | Key elements |
| Identifying triggers of RNT and stress | - *Challenge:* Personal warning signs<br>- *Mood tracker* | Identifying triggers of RNT and stress | - *Challenge:* Personal warning signs |
| Concreteness training | - *Challenge*: Abstract versus concrete thinking<br>- *Tool:* Concrete thinking | Concreteness training | - *Challenge*: Abstract versus concrete thinking<br>- *Tool*: Concrete thinking |
| Engaging in opposite Action | - *Tool:* Opposite Action | | |
| Self-compassion | - *Challenge:* Kind versus unkind self-talk<br>*Tool: Kind self-talk* | | |
| Mindfulness | - *Tool: Mindfulness* | | |
| Setting priories | - *Tool:* Setting priorities | | |
| Transfer to everyday life | - *If-then-plans* | Transfer to everyday life | - *If-then-plans* |

*Note*. Both interventions will be delivered via a self-help app. RNT = repetitive negative thinking.

## Figure 1

*CONSORT Trial Flow Chart*




*Note*. RNT = repetitive negative thinking, MDE = Major Depressive Episode, GAD = Generalized Anxiety Disorder, SAD = Social Anxiety Disorder.

**Table 2**

*Sample Characteristics and Mean Scores on Questionnaires (with SDs) at Baseline*

| Variable | | Condition | | |
|---|---|---|---|---|
| | | Waitlist Control *n* = 122 | Full RNT-Focused Intervention *n* = 122 | Concreteness Training Intervention *n* = 121 |
| Gender | female | 78.69% | 78.69% | 79.34% |
| | male | 20.49% | 20.49% | 19.83% |
| | non-binary | 0.82% | 0.82% | 0.83% |
| Highest educational degree | none | | 0.83% | 0.83% |
| | Hauptschulabschluss | | 0.83% | |
| | secondary school | 4.92% | 5.00% | 4.13% |
| | apprenticeship | 2.46% | 3.33% | 1.65% |
| | A level | 85.25% | 86.67% | 88.43% |
| | university degree | 7.38% | 3.33% | 4.96% |
| Current occupation | high school student | 7.38% | 6.56% | 5.00% |
| | university student | 78.69% | 79.51% | 82.64% |
| | apprenticeship | 4.10% | 4.10% | 4.13% |
| | employee | 5.74% | 5.74% | 1.65% |
| | self-employed | | | 0.83% |
| | voluntary service | | | 3.31% |
| | gap year | 3.28% | 1.64% | 0.83% |
| | none | 0.82% | 1.64% | |
| | other | | 0.82% | 1.65% |
| Any medication | yes | 29.51% | 36.89% | 33.10% |
| Age in years | | 19.98 (1.47) | 20.18 (1.37) | 20.17 (1.39) |
| PHQ-9 total score | | 5.88 (2.11) | 5.43 (2.30) | 5.83 (2.24) |
| IDS total score | | 15.16 (6.26) | 15.85 (7.19) | 16.73 (8.27) |
| GAD-7 total score | | 5.55 (2.07) | 5.20 (2.16) | 5.31 (2.29) |
| GADQ-IV total score | | 6.35 (2.05) | 6.18 (2.20) | 6.66 (2.03) |
| SIAS total score | | 24.08 (8.35) | 21.88 (8.97) | 23.45 (8.73) |
| SPIN total score | | 18.93 (8.87) | 18.21 (9.22) | 18.46 (8.84) |
| RRS total score | | 49.16 (7.63) | 49.70 (7.85) | 50.79 (7.37) |
| PSWQ total score | | 54.33 (8.45) | 53.91 (8.87) | 54.01 (7.96) |
| PTQ total score | | 33.02 (8.79) | 32.27 (8.87) | 33.15 (8.35) |

*Note*. Any medication = Taking any prescription medication, Hauptschulabschluss = German degree after 9 years of school, PHQ-9 = Patient Health Questionnaire-9, IDS = Inventory of Depressive Symptomatology, GAD-7 = Generalized Anxiety Disorder-7 Questionnaire, GADQ-IV = Generalized Anxiety Disorder Questionnaire-IV, SIAS = Social Interaction Anxiety Scale, SPIN = Social Phobia Inventory, RRS = Ruminative Response Scale, PSWQ = Penn State Worry Questionnaire, PTQ = Perseverative Thinking Questionnaire.

**Table 3**

*Means (with SDs) for Scores Primary and Secondary Outcome Measure(s) by Time and Condition*

| | Baseline | | | Post-Intervention | | | Follow-Up | | |
|---|---|---|---|---|---|---|---|---|---|
| | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention |
| IDS | 15.16 (6.26) | 15.85 (7.19) | 16.73 (8.27) | 13.81 (8.16) | 12.23 (5.80) | 15.26 (9.99) | 14.74 (9.60) | 14.49 (12.35) | 18.40 (13.07) |
| GADQ-IV | 6.64 (2.26) | 6.57 (2.44) | 6.99 (2.25) | 5.63 (2.63) | 5.62 (2.48) | 6.24 (2.77) | 6.25 (2.76) | 5.75 (2.51) | 6.15 (2.80) |
| SPIN | 18.93 (8.87) | 18.21 (9.22) | 18.46 (8.84) | 18.91 (10.88) | 17.75 (10.02) | 20.34 (11.44) | 20.32 (10.66) | 20.44 (13.17) | 21.76 (12.21) |
| RRS | 49.16 (7.63) | 49.70 (7.85) | 50.79 (7.37) | 47.97 (10.17) | 46.72 (10.26) | 48.12 (9.49) | 47.42 (9.99) | 47.02 (11.58) | 48.24 (10.54) |
| PSWQ | 54.33 (8.45) | 53.91 (8.87) | 54.01 (7.96) | 52.56 (9.73) | 51.45 (8.84) | 52.91 (9.42) | 53.49 (9.89) | 50.84 (10.60) | 53.07 (10.32) |
| PTQ | 33.02 (8.79) | 32.27 (8.87) | 33.15 (8.35) | 28.80 (10.17) | 28.93 (10.18) | 30.92 (11.59) | 29.84 (11.00) | 28.56 (10.99) | 29.62 (10.84) |

*Note.* Descrptive statistics were calculated for the intention-to-treat sample using complete cases at each time point. IDS = Inventory of Depressive Symptomatology, GADQ-IV = Generalized Anxiety Disorder Questionnaire-IV, SPIN = Social Phobia Inventory, RRS = Ruminative Response Scale, PSWQ = Penn State Worry Questionnaire, PTQ = Perseverative Thinking Questionnaire.

**Table 4**

*Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ-IV), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| **Outcome** | **IDS** | | **GADQ-IV** | | **SPIN** | | **RRS** | | **PSWQ** | | **PTQ** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* |
| Condition [full RNT-focused intervention] | 0.75<br>-1.20 – 2.69 | .452 | -0.07<br>-0.68 – 0.54 | .831 | -0.71<br>-3.13 – 1.71 | .563 | 0.53<br>-1.63 – 2.69 | .629 | -0.42<br>-2.61 – 1.78 | .709 | -0.75<br>-3.11 – 1.62 | .536 |
| Condition [concreteness training intervention] | 1.57<br>-0.38 – 3.52 | .115 | 0.35<br>-0.26 – 0.96 | .262 | -0.46<br>-2.89 – 1.96 | .708 | 1.63<br>-0.54 – 3.79 | .140 | -0.32<br>-2.52 – 1.88 | .776 | 0.13<br>-2.24 – 2.50 | .913 |
| Time [post-intervention] | -1.11<br>-2.46 – 0.25 | .109 | **-0.95**<br>**-1.36 – -0.54** | **<.001** | 0.13<br>-1.37 – 1.64 | .861 | -1.13<br>-2.74 – 0.47 | .167 | **-1.61**<br>**-3.01 – -0.22** | **.023** | **-3.85**<br>**-5.57 – -2.13** | **<.001** |
| Condition [full RNT-focused intervention]*time [post] | -1.63<br>-3.69 – 0.44 | .122 | 0.19<br>-0.43 – 0.82 | .541 | -1.72<br>-4.03 – 0.59 | .145 | -1.97<br>-4.42 – 0.49 | .117 | -0.78<br>-2.92 – 1.37 | .478 | 0.62<br>-2.01 – 3.25 | .645 |
| Condition [concreteness training intervention] *time [post] | -0.12<br>-2.15 – 1.91 | .909 | 0.21<br>-0.40 – 0.82 | .500 | 1.46<br>-0.80 – 3.72 | .207 | -1.24<br>-3.65 – 1.17 | .312 | 0.60<br>-1.50 – 2.70 | .578 | 1.61<br>-0.98 – 4.19 | .223 |
| **Random Effects** | | | | | | | | | | | | |
| $\sigma^2$/ $\tau_{00}$ | 24.61 /35.06 | | 2.26/ 3.63 | | 30.51/ 62.45 | | 35.41/ 38.72 | | 26.34/ 50.13 | | 40.53/ 48.13 | |
| *ICC*/ *N* (participants) | 0.59/ 364 | | 0.62/ 365 | | 0.67/ 365 | | 0.52/ 365 | | 0.66/ 365 | | 0.54/ 365 | |
| Observations | 610 | | 614 | | 614 | | 614 | | 614 | | 614 | |
| Marginal / Conditional $R^2$ | .021 / .596 | | .034 / .630 | | .009 / .675 | | .021 / .532 | | .010 / .659 | | .030 / .557 | |

*Note*. Outcomes are total scale scores on the respective measure. The models were estimated based on the intention-to-treat sample. Reference level for condition is the waitlist control condition and reference level for time is baseline. Post = post-intervention, $\sigma^2$= within-participant variability, $\tau_{00}$ = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional $R^2$= Proportion of variance explained by fixed/ by fixed and random effects.

**Table 5**

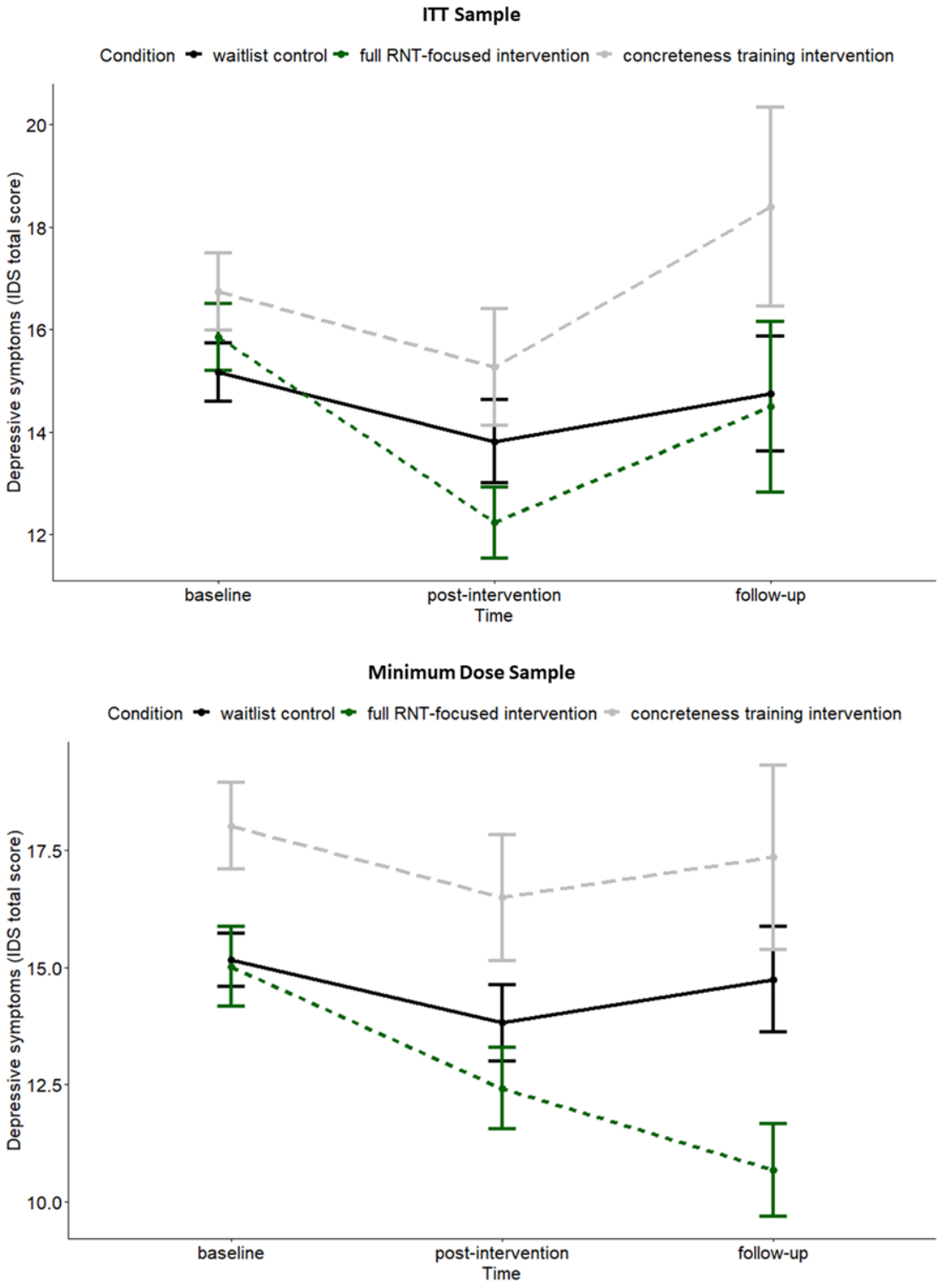
*Effect Sizes for Differences in Estimated Marginal Means of the Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ-IV), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| Contrast | Cohen's *d* | | | | | |
|---|---|---|---|---|---|---|
| | IDS | GADQ-IV | SPIN | RRS | PSWQ | PTQ |
| Waitlist control – full RNT-focused intervention [baseline] | -0.07 | 0.02 | 0.05 | -0.04 | 0.03 | 0.06 |
| Waitlist control – concreteness training intervention [baseline] | -0.14 | -0.11 | 0.03 | -0.13 | 0.03 | -0.01 |
| Full RNT-focused – intervention concreteness training intervention [baseline] | -0.08 | -0.13 | -0.02 | -0.09 | -0.01 | -0.07 |
| Waitlist control – full RNT-focused intervention [post-intervention] | 0.08 | -0.04 | 0.18 | 0.12 | 0.10 | 0.01 |
| Waitlist control – concreteness training intervention [post-intervention] | -0.13 | -0.18 | -0.07 | -0.03 | -0.02 | -0.13 |
| Full RNT-focused – intervention concreteness training intervention [post-intervention] | -0.21 | -0.14 | -0.02 | -0.15 | -0.12 | -0.14 |
| Baseline – post-intervention [wait list control] | 0.10 | 0.31 | -0.01 | 0.09 | 0.13 | 0.29 |
| Baseline – post-intervention [full RNT-focused intervention] | 0.25 | 0.24 | 0.12 | 0.25 | 0.20 | 0.24 |
| Baseline – post-intervention [concreteness training intervention] | 0.11 | 0.24 | -0.12 | 0.20 | 0.08 | 0.17 |

*Note*. Outcomes in the linear mixed-effects models are total scale scores on the respective measure.The models were estimated based on the intention-to-treat sample.

**Figure 2**

*Mean Depressive Symptoms with Standard Error Bars over the Course of the Trial by Condition*




*Note.* ITT = Intention-to-treat.

# 7. General Discussion

RNT is a crucial factor in various mental disorders. In addition, RNT is particularly prevalent in adolescents and young adults. Therefore, interventions with a focus on reducing RNT appear promising for addressing the increasing rates of mental health problems in these age groups. While the association between the overall construct RNT and psychopathology is well-evidenced, the understanding of several more specific aspects of this association is still limited. The first aim of this dissertation was to expand this previously limited scope. *Study I* and *II* analyzed associations between specific features of RNT (thought content and process features, stable and dynamic features) and symptoms of depression and anxiety. The results of both studies have implications for how to measure RNT. *Study III* investigated the association between RNT (worrying) and somatic generalized anxiety symptoms within the context of underlying genetic and environmental factors.

Furthermore, there are unresolved questions regarding RNT-focused interventions, which the second part of this dissertation sought to address. First, the processes through which RNT-focused interventions lead to change are still underinvestigated. To fill this gap, *Study IV* examined emotional reactivity as a potential mechanism of change and *Study V* investigated whether concreteness training is an active ingredient of RNT-focused interventions. Second, the limited scalability of RNT-focused interventions, which have been designed for an in-person format, presents a challenge. *Study IV* and *V* addressed this issue by exploring whether smartphone apps are suitable formats for increasing the scalability of RNT-focused interventions.

**Summary of Findings**

*Study I* investigated common and unique features of different RNT forms. Results showed that a common factor representing shared features of different RNT forms was the best predictor for depressive and anxiety symptoms. On a qualitative level, this common factor more likely reflects process features shared across different forms of RNT (i.e., the thinking is repetitive, intrusive and uncontrollable; Ehring et al., 2011) than a particular type of thought content. Supporting this notion, the Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011), which was designed to measure process features of RNT, yielded the highest loadings on the common RNT factor among all RNT questionnaires in the study. Hence, the results indicate that process rather than content features of RNT explain its negative effects on mental health.

All RNT measures used in *Study I* were trait questionnaires, which might lead to biased estimates due to retrospective recall. To account for the fact that RNT is a dynamic process, *Study II* investigated an EMA tool designed to assess process features of RNT in daily life in (nearly) real time. The results of the study showed that the average score on the EMA-based RNT measure was a more consistent predictor of depressive symptoms, anxiety symptoms and mental well-being than scores on the established trait RNT measures. Additionally, the study analyzed different patterns in the temporal dynamics of RNT as predictors of psychopathology. There were some indications for an association between RNT inertia (change resistance of RNT scores during the EMA period) and depressive symptoms, but the results were less consistent than for average scores on the EMA measure. Overall, the findings of *Study II* suggest that measuring RNT in daily life using EMA provides additional value for predicting psychopathology.

*Study III* examined the association between RNT (worrying) and somatic generalized anxiety symptoms in the context of underlying etiological factors. At the phenotypic level, the results showed that worrying and somatic generalized anxiety symptoms represent two distinct and well-replicable dimensions of generalized anxiety in young adulthood. Genetic factors underlying the two dimensions were mostly shared. Environmental influences also showed substantial overlap, but relative to genetic factors exhibited more specificity to the single dimensions. This implies that differences between worrying and somatic generalized anxiety symptoms are rather attributable to environmental than to genetic factors. Moreover, the study's results highlight the importance of differentiating between stable and dynamic components when investigating the etiology of RNT and associated psychopathology; when extracting the temporally stable component of generalized anxiety as well as its worrying and somatic anxiety dimension, heritability estimates increased considerably.

*Study IV* investigated the effects on an app-based RNT-focused intervention on emotional reactivity in response to stress to offer insights into a putative mechanism of change of RNT-focused interventions. Results demonstrated that the intervention attenuated the subjective responses to a standardized laboratory stressor; participants in the intervention condition showed more optimistic anticipatory stress appraisals, less RNT and faster affective recovery post-stressor relative to participants in the waitlist control condition. In contrast, the study did not find effects of the intervention on biological markers for stress responses. In summary, the findings of *Study IV* indicate that RNT-focused interventions might break the

self-perpetuating cycle of RNT, negative cognitive appraisals and negative affect in response to stress, thereby reducing depression and anxiety in the long term.

*Study V* tested the effects of a similar app-based intervention on subclinical depressive and anxiety symptoms within a prevention RCT. To investigate a putative active ingredient, two versions of the intervention app, the full RNT-focused intervention and a leaner intervention focused on training concrete thinking only, were compared to a waitlist control condition. Neither of the apps reduced depressive symptoms, anxiety symptoms and RNT relative to the waitlist. However, participants in the full-RNT focused intervention condition who used the app with a pre-defined minimum frequency reported greater baseline to follow-up decreases in depressive symptoms, generalized anxiety symptoms and RNT relative to the waitlist. While these results are encouraging, they do not support the notion that concreteness training is an active ingredient of RNT-focused interventions.

The results of *Study IV* and *V* also give indications for how to increase the scalability of RNT-focused interventions while preserving their efficacy. Although the comparability of the two studies is limited due to their different outcomes, it is striking that *Study IV* found effects of the app-based intervention on subjective stress responses, whereas *Study V* only found effects on depressive and anxiety symptoms in a subgroup of participants. These differences could be attributable to differences in app usage rates, which were substantially higher in *Study IV*. Considering that both apps employed the same contents, it is conceivable that the differences in usage rates and effects resulted from the different degrees of structure within the apps. In *Study IV*, the app followed a structured 10-day plan with designated exercises for each day, whereas the app in *Study V* administered the same intervention contents in a more flexible manner and over a longer period. Taken together, the two studies suggest that targeting RNT via self-help app can have positive effects on mental health, but only when the app is used frequently. In addition, a clear structure appears to promote frequent app usage.

## Discussion of Findings Concerning Associations Between Specific Features of RNT and Psychopathology

The findings of *Study I* and *II* help to understand the association between the overall construct RNT and psychopathology on a more granular level. The results suggest that process rather than content features and actual levels of RNT in daily life rather than retrospective estimates of the own tendency towards RNT are predictive of depressive and anxiety symptoms.

However, *Study I* and *II* do not give exhaustive answers regarding the association between thought process or temporal features of RNT and psychopathology. First, future studies should test whether the results of *Study I* and *II* replicate when including a broader range of psychopathological symptoms, e.g., disordered eating behaviors or post-traumatic stress symptoms. It is crucial to investigate whether specific features of RNT are equally important to the development and maintenance of different kinds of psychopathology, since the overall construct RNT has been linked to a broader range of disorders beyond depression and anxiety disorders (Ehring & Watkins, 2008; Grierson et al., 2016; Watkins & Roberts, 2020). Second, regarding process features of RNT, more research is needed to understand whether there are additional features aside from repetitiveness, intrusiveness and uncontrollability. For instance, it has been suggested that abstractness of thinking may be an additional process feature of RNT, shared across different forms of RNT and contributing to the negative consequences of RNT (Watkins, 2008). Yet, recent evidence contradicts this notion. For example, a high level of abstractness did not explain the negative consequences of anger rumination in a recent experimental study (Heinzel et al., 2023). As prior studies on the shared features of different RNT forms have primarily focused on the overlap between on worrying and rumination (e.g., Spinhoven et al., 2018; Taylor & Snyder, 2021; Topper et al., 2014), future studies should include other types of RNT such as post-event processing (Rachman et al., 2000) or anger rumination (Anestis et al., 2009). Third, with regards to dynamic features of RNT, *Study II* did not provide conclusive evidence regarding effects of different patterns in the dynamics of RNT on psychopathology. Future EMA studies should more systematically investigate RNT dynamics, including short-term and long-term changes, as well as interactions between average levels of RNT and indices of change resistance (e.g., RNT inertia).

Despite these unresolved questions, the findings of *Study I* and *II* have implications for clinical practice. Among all RNT measures in *Study I*, the PTQ assessing repetitiveness, intrusiveness and uncontrollability of RNT demonstrated the highest loadings on the common RNT factor, which in turn emerged as the strongest predictor of depressive and anxiety symptoms. In *Study II*, the EMA measure, which was constructed based on the PTQ, outperformed the trait measures of rumination and worrying in the prediction of depressive symptoms, anxiety symptoms and well-being. This highlights the usefulness of the PTQ for efficiently assessing process features of RNT that are relevant to the development of different types of psychopathology. In terms of clinical application, assessing whether scores on the PTQ decrease over the course of treatment could be a way of checking whether a patient is on track

toward recovery. Additionally, the finding that the average scores on the EMA-based RNT measure in *Study II* outperformed trait RNT measures in the prediction of psychopathology indicates that EMA has potential for clinical practice. For instance, a pre-intervention EMA phase including a measure of RNT could be a more valid way to select individuals who are likely to benefit from RNT-focused interventions than merely relying on trait RNT questionnaires. Moreover, administering EMA at different time points throughout an RNT-focused intervention would be helpful for assessing whether patients are able to transfer the acquired strategies into their daily lives.

**Discussion of Findings Concerning Genetic and Environmental Factors Underlying RNT and Associated Psychopathology**

The findings of *Study III* contribute to understanding the association between RNT and psychopathology in the context of underlying genetic and environmental factors. It is important to note that while *Study I* and *II* conceptualized RNT as a psychological risk factor for psychopathology, *Study III* investigated a particular form of RNT, namely worrying, as a symptom of psychopathology, specifically as a symptom of generalized anxiety. The results showed that while worrying and somatic anxiety symptoms represent distinct dimensions of generalized anxiety, genetic factors underlying the two dimensions are largely shared. Environmental factors also overlapped substantially, but relative to genetic factors showed more specificity to the single dimensions. This pattern of high genetic overlap and some environmental specificity is similar to the one found by studies investigating the etiological overlap between rumination and depressive symptoms (Chen & Li, 2013; Johnson et al., 2016; Johnson et al., 2014). However, the pattern differs from findings on the genetic overlap between rumination and other types of symptoms; Genetic factors were found to overlap only moderately between rumination and disordered eating and there was almost no overlap in the genetic factors explaining rumination and substance dependence (Johnson et al., 2016). Interestingly, depression and generalized anxiety cluster under the same subfactor within the Hierarchical Taxonomy of Psychopathology (HiToP; Conway et al., 2019), whereas disordered eating and substance dependence cluster under other subfactors. HiToP clusters different types of psychopathology based on the frequency of co-occurrence. It appears logical that types of psychopathology that commonly co-occur would share etiological pathways. The genetic risk for the distress subfactor that includes depression and generalized anxiety might be mediated by RNT.

At the same time, findings regarding the etiological overlap between worrying and somatic generalized anxiety symptoms, as well as between rumination and depressive symptoms, face one important limitation. Worrying is a symptom of generalized anxiety and rumination, despite not being a symptom of depression in the narrower sense, is likely to occur as a byproduct of depressive symptoms. As such, worrying and rumination are likely confounded with anxiety and depressive symptoms, respectively. Considering the results of *Study I* and *II*, future research should include a measure of process features of RNT, as these more purely reflect RNT as a broad risk factor for different types of psychopathology. It could even be argued that process features of RNT might reflect an endophenotype (Scaini et al., 2021), i.e., a more stable phenotype with clearer genetic connection, that explains the high genetic overlap between a wide range of mental disorders (Allegrini et al., 2020; Selzam et al., 2018). Including measures such as the PTQ (Ehring et al., 2011) in twin or genome-wide association studies could provide an efficient opportunity to identify shared genetic origins of different disorders.

Regarding studies aiming to understand environmental factors underlying RNT and associated mental disorders, the specificity found in *Study III* suggests that research on specific risk factors for particular types of psychopathological symptoms is warranted. The study's results suggest that certain environmental influences raise the risk for somatic generalized anxiety symptoms but not for worrying, and vice versa. However, identifying specific environmental risk factors for particular types of psychopathology, including particular forms of RNT like worrying, poses a challenge. Established environmental risk factors such as childhood trauma show associations with RNT (Kim et al., 2017) but also with psychopathology in general (McKay et al., 2021) and are therefore likely non-specific. The concept of moderators that raise concerns which are more directly related to certain symptoms (Nolen-Hoeksema & Watkins, 2011) could inform studies on more specific risk factors. For instance, insecurities arising from the transition between education and employment (Klug et al., 2019) could be important factors with regards to specific risks for worrying, which might also explain the high prevalence of worrying in young adulthood (Gonçalves & Byrne, 2013). Additionally, it is important to keep in mind that the influence of many environmental factors is likely rather transient, considering that most of the variance in stable generalized anxiety in *Study III* was explained by genetic factors.

## Discussion of Findings Concerning Active Ingredients and Mechanisms of Change of RNT-Focused Interventions

The second part of this dissertation (*Study IV* and *V*) aimed to better understand the processes through which RNT-focused interventions lead to change to provide indications for how to further improve these interventions. *Study IV* investigated emotional reactivity in response to stress as a putative mechanism of change and *Study V* examined concreteness training as a potential active ingredient of RNT-focused interventions.

The findings of *Study IV* suggest that change in emotional reactivity in response to stress could be a mechanism of change of RNT-focused interventions. Based on the results, it is conceivable that RNT-focused interventions can break the dysfunctional cycle of RNT, maladaptive cognitive appraisals and prolonged negative affect in response to stress, which, in the long term, might reduce depressive and anxiety symptoms. However, more research is needed to establish change in emotional reactivity as a mechanism of change of RNT-focused interventions. In an influential concept paper, Kazdin (2007) proposed several requirements that must be met before declaring a process a mechanism of change of an intervention. *Study IV* represents a first step by demonstrating that the intervention has an effect on the hypothesized mechanism. The next steps should include studies testing whether experimental manipulation of emotional reactivity leads to change in outcomes, such as reduced depressive symptoms, and studies analyzing whether change in emotional reactivity during an RNT-focused intervention precedes change in outcomes. If such studies can confirm that change in emotional reactivity is a mechanism of change of RNT-focused interventions, this would help to further improve these interventions. For example, the absence of change in emotional reactivity in a patient would then suggest that the RNT-focused intervention might not be working as it should for this patient and needs to be adjusted.

While *Study IV* focused on the overall effects of an RF-CBT-based intervention, *Study V* aimed to dissect the effects of one of the intervention's components by testing concreteness training as a stand-alone intervention. The results of *Study V* challenge the notion that concreteness training is an active ingredient of RNT-focused interventions, as it did not reduce depressive and anxiety symptoms relative to the waitlist control condition. However, the study likely has some methodological limitations, since the expected effects neither emerged in the full RNT-focused intervention condition (see following section). Considering that the null effects regarding the full RNT-focused intervention stand in contrast to previous trials testing

similar interventions (e.g., Cook et al., 2019; Topper et al., 2017), more research is needed before dismissing concreteness training as an active ingredient of RF-CBT.

It should be acknowledged that research on mechanisms of change and active ingredients of interventions is challenging. Some researchers have argued that the complexity of psychological interventions cannot be adequately reflected in simple models of change, where an isolated intervention component or mechanism leads to a particular outcome (Lemmens et al., 2016). Instead, studies investigating multiple mechanisms of change as well as their interactions or studies combining research on active ingredients and mechanisms of change might be more promising (Lemmens et al., 2016). In addition, which components work and how they work could be idiographic, calling for research designs that move beyond the group level (Lorenzo-Luaces, 2023).

**Discussion of Findings Concerning the Scalability of RNT-Focused Interventions**

In addition to examining processes through which RNT-focused interventions lead to change, *Study IV* and *V* investigated smartphone apps as means of increasing scalability of RNT-focused interventions for adolescents and young adults. As a first result, rates of app usage differed substantially between the two studies, even though the intervention contents were the same. The vast majority of participants (78%) in *Study IV* completed all exercises in the app on at least 9 of the 10 intervention days. On average, participants approximately used the app for 115 minutes over the course of the 10-day intervention and variance in usage rates was low. In contrast, in *Study V*, participants used the app for an average of approximately 60 minutes over the six-week intervention period. Moreover, the usage rates in *Study V* varied significantly between participants. A possible reason for this difference is the fact that the intervention in *Study IV* followed a structured plan with designated exercises in the app each day, whereas the app in *Study V* offered less guidance. An unstructured format in which participants can flexibly choose how they want to use the app has the advantage that users can adjust the intervention to their current needs. However, based on the findings of this dissertation, it is likely that a higher degree of structure is needed to keep users engaged consistently.

It is crucial to think about ways to raise usage rates of app-based interventions, as accumulating evidence suggests that the effects of mental health apps are highly dependent on how much the apps are used (Crookston et al., 2017). Consistent usage appears particularly important when aiming to reduce RNT via an app, considering that RNT is commonly

conceptualized as a mental habit (Watkins & Nolen-Hoeksema, 2014) and it likely takes repeated practice to form more helpful habits. Of course, comparing results of *Study IV* and *V* does not allow definitive conclusions about the role of usage rates as study designs and outcomes were different. However, it is striking that *Study IV* found effects of the app-based intervention on subjective stress reactivity, whereas *Study V* overall did not find effects on depressive symptoms, anxiety symptoms and RNT. Further supporting the importance of consistent app usage, a subgroup in *Study V*, who used the app to a pre-defined minimum extent, experienced significant improvements (e.g., less depressive symptoms). Arguably, these effects were only found in the full RNT-focused intervention condition and not in the concreteness training only condition. However, considering that usage rates in the concreteness training only condition were significantly lower than in the full RNT-focused intervention condition, the null findings with regards to effects of the concreteness training app could be due to too little practice of concrete thinking. The findings, together with earlier research on scalable app- and web-based RNT-focused interventions (Cook et al., 2019; Edge et al., in press; Topper et al., 2017), indicate that these interventions can be efficacious – as long as a certain intervention adherence is ensured.

**General Strengths and Limitations**

Note that the following sections lists overarching strengths and limitations of all five studies. For a more detailed discussion of the strengths and limitations of the single studies, the reader is referred to the respective sections of the single chapters.

One strength of this dissertation is that it combines basic research on the association between RNT and psychopathology with more applied studies testing the effects of interventions designed to reduce RNT. Ehring et al. (2022) proposed a framework for how basic research in clinical psychology can lead to more effective interventions for mental health problems. They outlined several steps in the translational chain, from identifying processes associated with symptoms of mental disorders over establishing causality of the process to the development and implementation of interventions designed to target the process of interest. Prior research on RNT has covered different steps in this translational model. Several studies have demonstrated associations between RNT and different types of psychopathology (e.g., Ryum et al., 2017; Spinhoven et al., 2018; Whisman et al., 2020; Wild et al., 2016). Experimental research has provided evidence that RNT is causally involved in the development and maintenance of mental disorders (Capobianco et al., 2018; Schaich et al., 2013; Watkins et

al., 2008; White & Wild, 2016). In addition, successful treatments for RNT have been developed based on these finding from basic research (Bell et al., 2023; Egan et al., 2024; Goldberg et al., 2018; McEvoy, 2019; Monteregge et al., 2020; Normann et al., 2014; Watkins, 2015). This dissertation addressed research gaps located at different stages of the translational chain.

*Study I* and *II* stepped back to the beginning of the translational chain by investigating which features of RNT are most strongly related to psychopathology. Their results suggest, amongst other things, that process features rather than content of RNT are predictive of depressive and anxiety symptoms. Importantly, according to an ideal translational chain (Ehring et al., 2022), experimental research on how process features of RNT can be addressed most effectively is warranted before translating these findings into actual interventions that can be tested in clinical RCTs. *Study IV* and *V* are situated closer to the end of the translational chain, providing evidence concerning the processes through which an existing RNT-focused intervention leads to change. If replicated, these findings could have implications for how to further improve the intervention. In addition, the two studies contribute to the last step in the translational chain by suggesting new ways to implement and potentially disseminate an existing RNT-focused intervention effectively on a larger scale.

An additional strength of this dissertation is the consistency in the measures used. With the exception of *Study III*, which focused specifically on worrying about the future, all studies included a thought-content-independent measure of process features of RNT. This consistency is particularly important when transitioning from basic research to more applied intervention studies. By using similar measures, it becomes possible to test whether findings from basic research have relevance for clinical application. For instance, *Study I* and *II* highlighted the potential of focusing on process features of RNT. *Study IV* showed that an app intervention based on RF-CBT can attenuate these features, i.e., participants in the intervention condition rated their thoughts as less intrusive, uncontrollable and repetitive post-stressor than participants in the control condition. As such, *Study IV* supports the applicability of the basic research findings in clinical practice.

Another strength is that most of the studies were conducted in adolescent and young adult samples. Understanding why mental health problems emerge and how they can be prevented and treated in these age groups is crucial, considering the rising rates depression and anxiety among individuals in their teenage years and early twenties (Archer et al., 2022;

Goodwin et al., 2022; Goodwin et al., 2020; Slee et al., 2021). It is important to note that the sample in *Study I* was substantially older with mean age with a mean age of 49 years. However, given that the study conceptually replicated earlier research in adolescents (Taylor & Snyder, 2021; Topper et al., 2014) with the main distinction being a broader set of RNT measures, it can be assumed that it's key findings translate to younger age groups.

Despite these strengths, this dissertation also has some overarching limitations. Firstly, all studies were conducted in sub-clinical or population samples, which raises concerns about the generalizability of findings to populations with diagnoses of mental disorders. However, there is accumulating evidence that mental health (problems) can better be described in terms of dimensions (e.g., *"to what extent does a person suffer from low mood?"*) than categories (e.g., *"does the person meet the cutoff for a diagnosis of depression?"*) (e.g., Haslam et al., 2020; Krueger et al., 2018; Smoller et al., 2019). Hence, studying phenomena such as RNT, anxiety symptoms or depressive symptoms in subclinical populations is informative. Still, while studies in individuals clearly falling into a particular diagnostic category are losing their former status, results of this dissertation should be replicated in samples with overall higher symptom burden. At the same time, it can be seen as a strength that the two intervention studies were conducted in individuals who did not meet the criteria for a full-blown mental disorder but were at risk for developing more severe mental health problems in the future. Investigating how to prevent mental disorders is a crucial step towards developing more holistic and efficient strategies for addressing mental health problems (Fusar-Poli et al., 2021).

A second limitation is that the majority of measures used in this dissertation were self-report measures. Future studies investigating similar RNT-focused interventions as *Study IV* and *V* should additionally comprise assessments by clinicians. In addition, future research should include biological markers to better understand the mechanisms linking RNT to mental disorders and underlying change resulting from RNT-focused interventions. In this dissertation, only one of the studies (*Study IV*) included biological measures. Of note, the study showed that the intervention affected subjective but not biological measures for stress reactivity, highlighting the lacking knowledge on the relationship between biological and psychological processes associated with psychopathology.

Another limitation concerns the age spans of the studies' samples. It is a clear strength that this dissertation focused on adolescents and young adults. However, future studies should include older reference groups. This particularly applies to studies investigating etiological

factors underlying RNT and associated psychopathology, as done in *Study III*. A design that compares otherwise matched younger and older age groups or one that tracks individuals longitudinally from early adolescence to mid-adulthood could help understand the factors driving the increase in mental health problems in the teenage years and early twenties. Similarly, trials comparing effects of RNT-focused interventions in different age groups could provide further information for how to reduce RNT most effectively in adolescents and young adults.

## Conclusion

This dissertation can be divided into two parts. The first three studies aimed to better understand the association between RNT and psychopathology, while the last two studies sought to provide new insights into how RNT-focused interventions for adolescents and young adults lead to change and how to increase the scalability of these interventions.

Building on the consistent finding that the overall construct of RNT is associated with psychopathology, *Studies I* and *II* investigated which features of RNT most likely account for this general association. *Study I* provided evidence that thought-content-independent process features, such as the repetitiveness, intrusiveness, and uncontrollability of negative thoughts, rather than thought content, predict depressive and anxiety symptoms. *Study II* demonstrated that the actual extent to which someone engages in RNT in daily life more consistently predicts depressive and anxiety symptoms than retrospective estimates of one's tendency towards RNT. The implications of these results include the need for RNT measures to capture process features and to assess RNT in daily life. *Study III* examined RNT and associated psychopathology within the context of underlying etiological factors. The results showed that the genetic factors underlying worrying, a form of RNT and a symptom of generalized anxiety, and somatic generalized anxiety symptoms are largely shared. In contrast, environmental factors were more specific to worrying and somatic generalized anxiety symptoms, respectively. Together with prior findings, these results suggest that the shared genetic risk for depression and anxiety might be mediated by RNT.

*Study IV* and *V* investigated processes through which RNT-focused interventions lead to change, while also exploring the use of smartphone apps as a means of increasing the scalability of these interventions. The results from *Study IV* indicate that changes in emotional reactivity in response to stress could be a mechanism of change in RNT-focused interventions. *Study V* did not find support for the notion that concreteness is an active ingredient of RNT-focused interventions; however, the null effects might have been due to the unstructured self-help app format of the intervention. Regarding increasing scalability, the findings of *Study IV* and *V* suggest that highly scalable self-help apps are suitable formats for reducing stress reactivity and subclinical depressive and anxiety symptoms in young people – but only when the apps are used frequently. Additionally, differences in app design and usage patterns between *Study IV* and *V* indicate that a clear structure with designated exercises for each new intervention day is beneficial for keeping app users engaged.

In sum, this dissertation has contributed to a better understanding of the association between RNT and psychopathology, with implications for the measurement of RNT. It has also provided new insights into the processes through which RNT-focused interventions might lead to change in adolescents' and young adults' psychopathology and has offered indications for how to increase the scalability of RNT-focused interventions for these age groups.

# 8. Zusammenfassung

Repetitives Negatives Denken bei Jugendlichen und Jungen Erwachsenen – Zentrale Merkmale, Ätiologische Faktoren und Psychologische Interventionen

Repetitives Negatives Denken (englisch: repetitive negative thinking; RNT), wie Sich-Sorgen oder Rumination, ist ein vielfach belegter Risiko- und Aufrechterhaltungsfaktor für verschiedene Arten von Psychopathologie, darunter Depression und Angststörungen. Besonders prävalent ist RNT unter Jugendlichen und jungen Erwachsenen. Daher ist dieser Prozess ein geeigneter Ansatzpunkt für Interventionen zur Reduktion von psychischen Problemen in diesen Altersgruppen. Zudem wurde die Wirksamkeit RNT-fokussierter Interventionen in der Prävention und Behandlung psychischer Störungen bereits empirisch belegt. Trotz dieser vielversprechenden Befunde gibt es in der vorhandenen Literatur noch einige ungeklärte Fragen. Diese betreffen sowohl die Forschung zur Assoziation von RNT und Psychopathologie als auch die Forschung zu RNT-fokussierten Interventionen.

Ziel des ersten Teils dieser Dissertation war es, die Assoziation zwischen RNT und Psychopathologie besser zu verstehen. *Studie I* und *II* untersuchten, welche Merkmale des komplexen Konstrukts RNT die besten Prädiktoren für eine Verschlechterung psychischer Gesundheit sind. Die Ergebnisse von *Studie I* legen nahe, dass Prozessmerkmale negativer Gedanken, z. B. deren Unkontrollierbarkeit, depressive Symptome und Angstsymptome besser vorhersagen als bestimmte Gedankeninhalte. *Studie II* zeigte, dass die tatsächliche Intensität von RNT im Alltag ein konsistenterer Prädiktor für Psychopathologie ist als retrospektive Schätzungen der eigenen Tendenz zu RNT. Zusammengenommen implizieren diese Befunde, dass bei der Messung von RNT besonderes Augenmerk auf Prozessmerkmale gelegt werden sollte und dass RNT im Alltag erfasst werden sollte. *Studie III* analysierte RNT und assoziierte Psychopathologie im Kontext zugrundeliegender ätiologischer Faktoren. Die Studie fand, dass genetische Faktoren, die Sich-Sorgen und somatischen generalisierten Angstsymptomen zu Grunde liegen, größtenteils überlappen. Zusammen mit früheren Befunden deutet dies darauf hin, dass das geteilte genetische Risiko für verschiedene Arten von Psychopathologie durch RNT mediiert sein könnte. Es sind jedoch weitere Studien notwendig, um diese Hypothese zu bestätigen.

Im zweiten Teil dieser Dissertation wurden Forschungslücken zu RNT-fokussierten Interventionen für Jugendliche und junge Erwachsene adressiert. *Studie IV* und *V* untersuchten mögliche Wirkmechanismen bzw. Wirkkomponenten, während gleichzeitig die Eignung von Smartphone-Apps für die Verbesserung der Skalierbarkeit der Interventionen untersucht wurde. *Studie IV* deutet darauf hin, dass eine Verringerung der emotionaler Reaktivität auf Stress ein Veränderungsmechanismus RNT-fokussierter Interventionen sein könnte. *Studie V* konnte die Annahme, dass das Training in konkretem Denken eine aktive Wirkkomponente RNT-

fokussierter Interventionen ist, die substanziell zu deren positiven Effekten beiträgt, nicht bestätigen. Es könnte jedoch sein, dass dies methodologischen Limitationen der Studie geschuldet ist. Im Hinblick auf die Skalierbarkeit zeigten die beiden Studien, dass hoch skalierbare Selbsthilfe-Apps geeignet sind, um Stressreaktivität sowie subklinische depressive Symptome und Angstsymptome zu reduzieren – aber nur, wenn eine häufige Appnutzung sichergestellt werden kann. Zusätzlich legen Unterschiede in Appdesign und Nutzungsmustern zwischen *Studie IV* und *V* nahe, dass eine klare Struktur mit vorgesehenen Übungen für jeden Tag förderlich für eine regelmäßige App-Nutzung ist.

Zusammengefasst hat die vorliegende Dissertation spezifische Merkmale des komplexen Konstrukts RNT identifiziert, die dessen Assoziation mit Psychopathologie erklären. Darüber hinaus hat diese Dissertation Evidenz zum Einfluss von genetischen Faktoren und Umweltfaktoren auf RNT und assoziierte Psychopathologie beigesteuert. Zudem hat sie Einblicke in Veränderungsmechanismen RNT-fokussierter Interventionen gewährt, die eine Reduktion von Psychopathologie bei Jugendlichen und jungen Erwachsen vermitteln könnten. Schließlich gibt diese Dissertation Hinweise darauf, wie die Skalierbarkeit RNT-fokussierter Interventionen für junge Menschen erhöht werden könnte, ohne dabei ihre Effektivität zu beeinträchtigen.

# List of Figures

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# Appendix A:

## Supplementary Material *Study I*

*The Bi-Factor Model of Repetitive Negative Thinking: Common vs. Unique Factors as Predictors of Depression and Anxiety*

Appendix A

## A. Overview SEM RNT Studies

## Table S1

*Characteristics of prior studies using SEM to investigate RNT*

| Citation | Sample | Content-dependent RNT measures | Content-independent RNT measures | RNT models tested | Prediction of psychopathological symptoms |
|---|---|---|---|---|---|
| Hur, J., Heller, W., Kern, J. L., & Berenbaum, H. (2017). A bi-factor approach to modeling the structure of worry and rumination. *Journal of Experimental Psychopathology, 8*(3), 252-264. https://doi.org/10.5127/jep.057116. | Undergraduate students (*N* = 564) | **Rumination**: Rumination/Reflection Questionnaire (RRQ; Trapnell & Campbell, 1999) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | none | Bi-factor model, separate-factor model, single-factor model<br><br>→ Bi-factor model fit the data well and demonstrated best fit relative to the other models | **Cross-sectional**: Common RNT factor of the bi-factor model predicted depressive and anxiety symptoms, scale-specific factors did not |
| Samtani, S., Moulds, M. L., Johnson, S. L., Ehring, T., Hyett, M. P., Anderson, R., & McEvoy, P. M. (2021). Higher Order Repetitive Negative Thinking Is More Robustly Related to Depression, Anxiety, and Mania Than Measures of Rumination or Worry. *Cognitive Therapy and Research*, 1-10. https://doi.org/10.1007/s10608-021-10235-3. | Undergraduate students *(N* = 2088) | **Rumination**: Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | Repetitive Thinking Questionnaire (RTQ; McEvoy et al., 2010) Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) | Bi-factor model<br><br>→ Bi-factor model demonstrated good fit | **Cross-sectional:** Common RNT factor of the bi-factor model predicted higher depressive and anxiety and lower mania symptoms, scale-specific RNT factors predicted symptoms on top of the common factor, but explained less variance |
| Spinhoven, P., Drost, J., van Hemert, B., & Penninx, B. W. (2015). Common rather than unique aspects of repetitive negative thinking are related to depressive and anxiety disorders and symptoms. *Journal of Anxiety Disorders, 33*, 45-52. https://doi.org/10.1016/j.janxdis.2015.05.001. | Participants with and without mood and anxiety disorders (*N* = 2143) | **Rumination**: Rumination on Sadness Sub-Scale of the Leiden Index of Depression Sensitivity (LEIDS-R; Van der Does, 2002, Williams et al., 2008) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) | Single-factor model with questionnaire sum scores (and not single items) as indicators<br><br>Bi-factor model was not tested in this paper, but was tested in the same data set (excl. dropout) in Spinhoven et al. (2918) | **Cross-sectional:** Common RNT factor indexed by RNT questionnaire sum scores predicted depressive and anxiety symptoms, unique variance of the rumination scale predicted depressive symptoms and unique variance of the worry scale predicted anxiety symptoms on top of the common factor |
| Spinhoven,P., van Hemert, A. M., & Penninx, B. W. (2018). Repetitive negative thinking as a predictor of depression and | Same sample as Spinhoven et al. (2015), additional measure- | **Rumination**: Rumination on Sadness Sub-Scale of the Leiden Index of Depression Sensitivity (LEIDS-R; Van der Does, | Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) | Bi-factor model, separate-factor model, single-factor model, second-order model | **Longitudinal:** (Controlling for initial symptom levels): The common RNT factor of the bi-factor model |

| | | | | | |
|---|---|---|---|---|---|
| anxiety: A longitudinal cohort study. *Journal of affective disorders, 241*, 216-225. https://doi.org/10.1016/j.jad.2018.08.037. | ment timepoint (*N* = 1972) | 2002, Williams et al., 2008) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | | → Bi-factor model fit the data well and demonstrated relative to the other models | predicted later depressive and anxiety symptoms, on top of the common factor, the scale-specific factors predicted symptoms, but explained less variance |
| Taylor, M. M., & Snyder, H. R. (2021). Repetitive Negative Thinking Shared Across Rumination and Worry Predicts Symptoms of Depression and Anxiety. *Journal of Psychopathology and Behavioral Assessment*, 1-12. https://doi.org/10.1007/s10862-021-09898-9. | Undergraduate students (*N* = 224) | **Rumination**: Rumination Reflection Questionnaire (RRQ, Trapnell & Campbell, 1999) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | none | Bi-factor model, separate-factor model, single-factor model<br><br>→ Bi-factor model fit the data well and demonstrated best fit relative to the other models | **Cross-sectional**: Common RNT factor of the bi-factor model predicted depressive and anxiety symptoms, scale-specific factors did not |
| Topper, M., Molenaar, D., Emmelkamp, P. M., & Ehring, T. (2014). Are rumination and worry two sides of the same coin? A structural equation modelling approach. *Journal of Experimental Psychopathology, 5*(3), 363-381. https://doi.org/10.5127/jep.038813. | Adolescents (N = 3906) → to test RNT models Undergraduate students (*N* = 108) → to test relations with depressive and anxiety symptoms | **Rumination**: Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991) **Worry**: Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) | none | Bi-factor model, separate-factor model<br><br>→ Bi-factor model fit the data well and demonstrated best fit relative to the other model | **Longitudinal:** (Controlling for initial symptom levels): Common RNT factor of the bi-factor model predicted depressive and anxiety symptoms, scale-specific factors did not |

*Note.* SEM = Structural equation modeling, RNT = Repetitive negative thinking.

## B. Item Formulation of the Lost Items of the Ruminative Response Scale (RRS)

The instructions at the beginning of the questionnaire read: *People think and do many different things when they feel sad, blue, or depressed. Please indicate what you generally do, when you feel down or sad, not what you think you should do.*; The four items that were lost due to a technical failure are formulated as follows. Item 1: *Think "What am I doing to deserve this?"*; Item 3: *Think "Why do I always react this way?"*; Item 8: *Think "Why can't I handle things better?*"; Item 10: "*Go someplace alone to think about your feelings"*

## C. Loadings of the Bi-Factor Model

### Table S2

*Factor Loadings of the bi-factor model*

| Item Name | C-factor | PTQ-factor | RTQ-factor | PSWQ-factor | RRS-factor |
|---|---|---|---|---|---|
| PTQ1 | 0.83 | 0.12 | | | |
| PTQ2 | 0.85*** | 0.17*** | | | |
| PTQ3 | 0.86*** | 0.16*** | | | |
| PTQ4 | 0.77*** | -0.10* | | | |
| PTQ5 | 0.66*** | -0.52*** | | | |
| PTQ6 | 0.86*** | 0.06* | | | |
| PTQ7 | 0.80*** | 0.18*** | | | |
| PTQ8 | 0.88*** | 0.02 | | | |
| PTQ9 | 0.79*** | 0.04 | | | |
| PTQ10 | 0.78*** | -0.46*** | | | |
| PTQ11 | 0.85*** | -0.08 | | | |
| PTQ12 | 0.66*** | 0.13** | | | |
| PTQ13 | 0.87*** | 0.08* | | | |
| PTQ14 | 0.74*** | -0.02 | | | |
| PTQ15 | 0.74*** | -0.38*** | | | |
| RTQ1 | 0.60*** | | 0.28 | | |
| RTQ2 | 0.75*** | | 0.36*** | | |
| RTQ3 | 0.60*** | | 0.19*** | | |
| RTQ4 | 0.65*** | | 0.38*** | | |
| RTQ5 | 0.83*** | | 0.26*** | | |
| RTQ6 | 0.63*** | | 0.34*** | | |
| PTQ7 | 0.70*** | | 0.44*** | | |
| RTQ8 | 0.77*** | | 0.26*** | | |
| RTQ9 | 0.77*** | | 0.31*** | | |
| RTQ10 | 0.65*** | | 0.41*** | | |
| PSWQ2 | 0.69*** | | | 0.39 | |
| PSWQ4 | 0.65*** | | | 0.51*** | |
| PSWQ5 | 0.69*** | | | 0.47*** | |
| PSWQ6 | 0.66*** | | | 0.45*** | |
| PSWQ7 | 0.66*** | | | 0.54*** | |
| PSWQ9 | 0.60*** | | | 0.46*** | |
| PSWQ12 | 0.64*** | | | 0.48*** | |
| PSWQ13 | 0.62*** | | | 0.46*** | |
| PSWQ14 | 0.74*** | | | 0.35*** | |
| PSWQ15 | 0.66*** | | | 0.50*** | |
| PSWQ16 | 0.56*** | | | 0.42*** | |
| RRS2 | 0.45*** | | | | 0.63 |
| RRS4 | 0.44*** | | | | 0.52*** |

| | | |
|---|---|---|
| RRS5 | 0.14** | 0.24*** |
| RRS6 | 0.58*** | 0.16*** |
| RRS7 | 0.52*** | 0.15** |
| RRS9 | 0.56*** | 0.56*** |

*Note*. C-RNT=Common RNT factor; PTQ-RNT=Perseverative Thinking Questionnaire RNT factor; RTQ-RNT=Repetitive Thinking Questionnaire RNT factor; PSWQ-RNT=Penn State Worry Questionnaire RNT factor; RRS-RNT=Ruminative Response Scale RNT factor; *** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$.

## D. Additional Factor Models of RNT

### *Reduced vs. full bi-factor model*

Next to the bi-factor model reported in the manuscript (full bi-factor model), we estimated an additional alternative bi-factor model, the reduced bi-factor model. This model consists of a common factor indexed by all RNT measures and scale-specific factors only for the content-dependent RNT measures (i.e., the Ruminative Response Scale - RRS, and the Penn State Worry Questionnaire - PSWQ) but not for the content-independent measures (i.e., the Preservative Thinking Questionnaire - PTQ, and the Repetitive Thinking Questionnaire RTQ). In contrast, the full bi-factor model has scale-specific factors for each RNT measure regardless of the content-(in)dependence next to the common RNT factor.

Compared to the full bi-factor model, $\chi^2(777) = 2113.51$, $p < .001$, CFI = .93, TLI = .92, RMSEA = .06, SRMR = .04, the reduced bi-factor model, $\chi^2(802) = 2969.19$, $p < .001$, CFI = .88, TLI = .87, RMSEA = .07, SRMR = .04, demonstrated poorer fit on almost all fit indices. In line with this, AIC and BIC showed lower values and therefore indicated better fit of the full bi-factor model (AIC = 48888.97, BIC = 49425.67) compared to the reduced bi-factor model (AIC = 50662.92, BIC = 51093.14).

### *Bi-factor model vs. second-order model*

We additionally tested a second-order model with one higher-order factor overarching four lower-order factors specified for each RNT scale. Unlike the bi-factor model, in which the scale-specific factors are independent of (orthogonal to) the common RNT factor, the second-order model assumes that the scale-specific factors are dependent of (subordinate to) the higher-order, common RNT factor. Compared to the bi-factor model, $\chi^2(777) = 2113.51$, $p <$

.001, CFI = .93, TLI = .92, RMSEA = .06, SRMR = .04, the second-order model, , $\chi^2(815)$ = 2685.47 , $p < .001$, CFI = .9, TLI = .89, RMSEA = .07, SRMR = .05, demonstrated poorer fit on all fit indices. In line with this, AIC and BIC demonstrated lower values and therefore indicated better fit of the bi-factor model (AIC = 48888.97, BIC = 49425.67) relative to the second-order model (AIC = 50353.20, BIC = 50728.04).

**E. Cross-Validation of RNT CFAs**

We cross-validated the three RNT models reported in the manuscript in two subsets of the data, which were not used in the main analyses. Specifically, we applied the same CFAs to: (a) the t1 RNT data of participants who did not complete t2; and (b) t2 RNT data of participants who completed both t1 and t2.

***Cross-Validation in data subset (a)***

The cross-validation sample (a) consisted of $N = 550$ participants. Similar to the main analyses, we excluded the data of participants who did not consent to the analysis of their data or who indicated that they did not answers the questions truthfully. For the bi-factor model, goodness of fit was acceptable on the CFI, TLI and RMSEA, and good on the SRMR, $\chi^2(777)$ = 2242.50, $p < .001$, CFI = .92, TLI = .91, RMSEA = .06, SRMR = .04. Compared to the bi-factor model, the single-factor model, $\chi^2(819) = 4685.729$, $p < .001$, CFI = .79, TLI = .78, RMSEA = .09, SRMR = .06, and the separate-factor model, $\chi^2(813) = 2727.670$, $p < .001$, CFI = .90, TLI = .89, RMSEA = .07, SRMR = .05, demonstrated a poorer fit on all fit indices. In line with this, AIC and BIC demonstrated lower values and therefore indicated better fit of the bi-factor model (AIC = 53416.74, BIC = 53959.79) compared to the separate-factor model (AIC = 53829.91, BIC = 54217.806) and the single-factor model (AIC = 55775.973, BIC = 56138.006).

Within the bi-factor model, we found a similar pattern of factors loadings as in the original bi-factor model. All loadings on the common factor were significant and positive. All loadings on the specific RTQ, PSWQ and RRS factors were significant and positive although mostly smaller than on the common factor. Loadings on the PTQ were inconsistent with some non-significant and some negative factor loadings (for more details see Table S3).

**Table S3.**

*Factor Loadings of the bi-factor model in cross-validation data subset (a)*

| Item Name | C-factor | PTQ-factor | RTQ-factor | PSWQ-factor | RRS-factor |
|---|---|---|---|---|---|
| PTQ1 | 0.79 | 0.31 | | | |
| PTQ2 | 0.81*** | 0.37*** | | | |
| PTQ3 | 0.84*** | 0.29*** | | | |
| PTQ4 | 0.74*** | -0.10* | | | |
| PTQ5 | 0.71*** | -0.27*** | | | |
| PTQ6 | 0.83*** | 0.19*** | | | |
| PTQ7 | 0.80*** | 0.22*** | | | |
| PTQ8 | 0.83*** | 0.17*** | | | |
| PTQ9 | 0.80*** | -0.01 | | | |
| PTQ10 | 0.80*** | -0.23*** | | | |
| PTQ11 | 0.82*** | 0.01** | | | |
| PTQ12 | 0.57*** | 0.20*** | | | |
| PTQ13 | 0.81*** | 0.10* | | | |
| PTQ14 | 0.76*** | -0.10* | | | |
| PTQ15 | 0.78*** | -0.24*** | | | |
| RTQ1 | 0.59*** | | 0.29 | | |
| RTQ2 | 0.74*** | | 0.41*** | | |
| RTQ3 | 0.68*** | | 0.16*** | | |
| RTQ4 | 0.60*** | | 0.43*** | | |
| RTQ5 | 0.81*** | | 0.29*** | | |
| RTQ6 | 0.58*** | | 0.34*** | | |
| PTQ7 | 0.56*** | | 0.41*** | | |
| RTQ8 | 0.77*** | | 0.26*** | | |
| RTQ9 | 0.78*** | | 0.32*** | | |
| RTQ10 | 0.67*** | | 0.37*** | | |
| PSWQ2 | 0.68*** | | | 0.43 | |
| PSWQ4 | 0.61*** | | | 0.57*** | |
| PSWQ5 | 0.66*** | | | 0.50*** | |
| PSWQ6 | 0.59*** | | | 0.40*** | |
| PSWQ7 | 0.67*** | | | 0.53*** | |
| PSWQ9 | 0.56*** | | | 0.47*** | |
| PSWQ12 | 0.62*** | | | 0.53*** | |
| PSWQ13 | 0.61*** | | | 0.47*** | |
| PSWQ14 | 0.72*** | | | 0.38*** | |
| PSWQ15 | 0.70*** | | | 0.51*** | |
| PSWQ16 | 0.49*** | | | 0.43*** | |
| RRS2 | 0.41*** | | | | 0.65 |
| RRS4 | 0.46*** | | | | 0.45*** |
| RRS5 | 0.17*** | | | | 0.29*** |

| | | |
|---|---|---|
| RRS6 | 0.54*** | 0.22*** |
| RRS7 | 0.56*** | 0.12** |
| RRS9 | 0.57*** | 0.46*** |

*Note*. C-RNT=Common RNT factor; PTQ-RNT=Perseverative Thinking Questionnaire RNT factor; RTQ-RNT=Repetitive Thinking Questionnaire RNT factor; PSWQ-RNT=Penn State Worry Questionnaire RNT factor; RRS-RNT=Ruminative Response Scale RNT factor; *** = $p$<0.001; ** = $p$<0.01; * = $p$<0.05.

***Cross-Validation in data subset (b)***

The cross-validation sample (b) consisted of $N$ = 523 participants (the same as the main analyses). For the bi-factor model, goodness of fit was acceptable on the CFI, TLI and RMSEA, and good on the SRMR, $\chi^2(777) = 2343.47$, $p < .001$, CFI = .92, TLI = .91, RMSEA = .06, SRMR = .04. Compared to the bi-factor model, the single-factor model, $\chi^2(819) = 4889.51$, $p < .001$, CFI = .79, TLI = .78, RMSEA = .10, SRMR = .06, and the separate-factor model, $\chi^2(813) = 2968.36$, $p < .001$, CFI = .89, TLI = .88, RMSEA = .07, SRMR = .05, demonstrated a poorer fit on all fit indices. In line with this, AIC and BIC demonstrated lower values and therefore indicated better fit of the bi-factor model (AIC = 48888.97, BIC = 49425.67) compared to the separate-factor model (AIC = 49441.86, BIC = 49825.22) and the single-factor model (AIC = 51351.00, BIC = 51708.81).

Within the bi-factor model, we found a similar pattern of factors loadings as in the original bi-factor model. All but one loading on the common factor were significant and positive. All loadings on the specific RTQ, PSWQ and RRS factors were significant and positive although mostly smaller than on the common factor. Loadings on the PTQ were inconsistent with some non-significant and some negative factor loadings (for more details see Table S4).

**Table S4.**

*Factor Loadings of the bi-factor model in cross-validation data subset (b).*

| Item Name | C-factor | PTQ-factor | RTQ-factor | PSWQ-factor | RRS-factor |
|---|---|---|---|---|---|
| PTQ1 | 0.85 | 0.226 | | | |
| PTQ2 | 0.84*** | 0.22*** | | | |

| | | | | | |
|---|---|---|---|---|---|
| PTQ3 | 0.87*** | 0.21*** | | | |
| PTQ4 | 0.78*** | -0.09* | | | |
| PTQ5 | 0.70*** | -0.45*** | | | |
| PTQ6 | 0.87*** | 0.13*** | | | |
| PTQ7 | 0.83*** | 0.11*** | | | |
| PTQ8 | 0.86*** | 0.08** | | | |
| PTQ9 | 0.82*** | -0.02 | | | |
| PTQ10 | 0.76*** | -0.46*** | | | |
| PTQ11 | 0.85*** | 0.03 | | | |
| PTQ12 | 0.64*** | 0.03 | | | |
| PTQ13 | 0.85*** | 0.05 | | | |
| PTQ14 | 0.73*** | -0.08* | | | |
| PTQ15 | 0.73*** | -0.35*** | | | |
| RTQ1 | 0.66*** | | 0.20 | | |
| RTQ2 | 0.73*** | | 0.43*** | | |
| RTQ3 | 0.66*** | | 0.15*** | | |
| RTQ4 | 0.64*** | | 0.42*** | | |
| RTQ5 | 0.84*** | | 0.23*** | | |
| RTQ6 | 0.64*** | | 0.34*** | | |
| PTQ7 | 0.71*** | | 0.46*** | | |
| RTQ8 | 0.77*** | | 0.25*** | | |
| RTQ9 | 0.80*** | | 0.32*** | | |
| RTQ10 | 0.67*** | | 0.33*** | | |
| PSWQ2 | 0.68*** | | | 0.41 | |
| PSWQ4 | 0.69*** | | | 0.50*** | |
| PSWQ5 | 0.68*** | | | 0.51*** | |
| PSWQ6 | 0.68*** | | | 0.44*** | |
| PSWQ7 | 0.70*** | | | 0.51*** | |
| PSWQ9 | 0.64*** | | | 0.43*** | |
| PSWQ12 | 0.63*** | | | 0.53*** | |
| PSWQ13 | 0.63*** | | | 0.46*** | |
| PSWQ14 | 0.74*** | | | 0.37*** | |
| PSWQ15 | 0.71*** | | | 0.47*** | |
| PSWQ16 | 0.60*** | | | 0.39*** | |
| RRS2 | 0.43*** | | | | 0.63 |
| RRS4 | 0.49*** | | | | 0.49*** |
| RRS5 | 0.07 | | | | 0.32*** |
| RRS6 | 0.53*** | | | | 0.19*** |
| RRS7 | 0.61*** | | | | 0.12** |
| RRS9 | 0.56*** | | | | 0.57*** |

*Note*. C-RNT=Common RNT factor; PTQ-RNT=Perseverative Thinking Questionnaire RNT factor; RTQ-RNT=Repetitive Thinking Questionnaire RNT factor; PSWQ-RNT=Penn State Worry Questionnaire RNT factor; RRS-RNT=Ruminative Response Scale RNT factor; *** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$.

# Appendix B:

## Supplementary Material *Study II*

*An Ecological Momentary Assessment Study Assessing Repetitive Negative Thinking as a Predictor for Psychopathology*

Appendix B

Tables S1-3 shows the results of linear regressions testing the effects of inertia and variability of repetitive negative thinking (RNT) on depressive symptoms, generalized anxiety symptoms and mental well-being, respectively. Tables S4-6 show the results of linear regressions testing the effects of RNT instability on the same outcomes.

**Table S1**

*Linear regressions testing the effects of RNT inertia and variability on depressive symptoms (sum score on the PHQ-9)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (inertia) | 1.36 (-0.16 – 2.88) | 0.06 | 0.080 | 2.59 (0.80 – 4.39) | 0.11 | **0.005** | 1.16 (-0.99 – 3.30) | 0.05 | 0.291 | 2.13 (-0.41 – 4.67) | 0.08 | 0.100 |
| $PTQ_{EMA}$ (variability) | -0.01 (-0.14 – 0.13) | -0.01 | 0.896 | 0.10 (-0.06 – 0.26) | 0.05 | 0.224 | 0.14 (-0.06 – 0.34) | 0.07 | 0.165 | 0.12 (-0.11 – 0.36) | 0.05 | 0.312 |
| $PTQ_{EMA}$ (mean) | 0.11 (0.04 – 0.19) | 0.14 | **0.003** | 0.23 (0.14 – 0.31) | 0.24 | **<0.001** | 0.21 (0.10 – 0.32) | 0.20 | **<0.001** | 0.11 (-0.02 – 0.24) | 0.09 | 0.107 |
| RRS-B at baseline | 0.27 (0.18 – 0.36) | 0.22 | **<0.001** | 0.12 (0.01 – 0.23) | 0.09 | **0.033** | 0.20 (0.06 – 0.33) | 0.13 | **0.004** | 0.09 (-0.07 – 0.25) | 0.06 | 0.266 |
| PSWQ-A at baseline | 0.15 (0.11 – 0.18) | 0.33 | **<0.001** | 0.02 (-0.03 – 0.06) | 0.03 | 0.463 | -0.06 (-0.11 – -0.00) | -0.10 | **0.039** | -0.00 (-0.07 – 0.06) | -0.00 | 0.943 |
| PHQ-9 at baseline | | | | 0.38 (0.29 – 0.47) | 0.33 | **<0.001** | 0.37 (0.26 – 0.48) | 0.29 | **<0.001** | 0.42 (0.28 – 0.55) | 0.30 | **<0.001** |
| Condition (self-monitoring) | | | | 0.35 (-0.31 – 1.02) | 0.09 | 0.297 | 0.26 (-0.56 – 1.07) | 0.06 | 0.537 | -0.42 (-1.40 – 0.55) | -0.09 | 0.395 |
| Condition (self-Monitoring + EC) | | | | 0.13 (-0.49 – 0.76) | 0.03 | 0.672 | -0.06 (-0.82 – 0.71) | -0.01 | 0.886 | -0.56 (-1.46 – 0.34) | -0.12 | 0.223 |
| Observations | 665 | | | 573 | | | 554 | | | 501 | | |
| $R^2$ / $R^2$ adjusted | 0.324 / 0.319 | | | 0.352 / 0.343 | | | 0.231 / 0.219 | | | 0.174 / 0.160 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table S2**

*Linear regressions testing the effects of RNT inertia and variability on generalized anxiety symptoms (sum score on the GAD-7)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (inertia) | -1.02 (-2.42 – 0.38) | -0.04 | 0.154 | 0.75 (-0.80 – 2.29) | 0.03 | 0.343 | -0.56 (-2.53 – 1.42) | -0.02 | 0.580 | 0.81 (-1.53 – 3.14) | 0.03 | 0.499 |
| $PTQ_{EMA}$ (variability) | -0.11 (-0.23 – 0.01) | -0.06 | 0.084 | 0.15 (0.01 – 0.29) | 0.08 | **0.042** | 0.25 (0.06 – 0.43) | 0.12 | **0.009** | 0.04 (-0.18 – 0.25) | 0.02 | 0.747 |
| $PTQ_{EMA}$ (mean) | 0.23 (0.16 – 0.29) | 0.25 | **<0.001** | 0.22 (0.14 – 0.30) | 0.23 | **<0.001** | 0.22 (0.11 – 0.32) | 0.21 | **<0.001** | 0.08 (-0.04 – 0.21) | 0.08 | 0.201 |
| RRS-B at baseline | 0.23 (0.15 – 0.31) | 0.18 | **<0.001** | -0.04 (-0.13 – 0.06) | -0.03 | 0.438 | 0.09 (-0.03 – 0.22) | 0.06 | 0.143 | 0.06 (-0.09 – 0.21) | 0.04 | 0.414 |
| PSWQ-A at baseline | 0.24 (0.21 – 0.27) | 0.49 | **<0.001** | 0.11 (0.07 – 0.15) | 0.23 | **<0.001** | 0.05 (-0.01 – 0.10) | 0.09 | 0.087 | 0.06 (0.00 – 0.13) | 0.12 | **0.046** |
| GAD-7 at baseline | | | | 0.38 (0.29 – 0.46) | 0.37 | **<0.001** | 0.31 (0.19 – 0.42) | 0.27 | **<0.001** | 0.31 (0.18 – 0.44) | 0.27 | **<0.001** |
| Condition (self-monitoring) | | | | -0.12 (-0.69 – 0.46) | -0.03 | 0.687 | -0.66 (-1.41 – 0.09) | -0.16 | 0.083 | -0.57 (-1.47 – 0.33) | -0.13 | 0.215 |
| Condition (self-Monitoring + EC) | | | | -0.35 (-0.89 – 0.18) | -0.09 | 0.193 | -0.41 (-1.10 – 0.29) | -0.10 | 0.252 | -0.35 (-1.18 – 0.47) | -0.08 | 0.402 |
| Observations | 665 | | | 575 | | | 554 | | | 501 | | |
| $R^2$ / $R^2$ adjusted | 0.506 / 0.502 | | | 0.507 / 0.500 | | | 0.316 / 0.306 | | | 0.191 / 0.177 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination; , self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table S3**

*Linear regressions testing the effects of RNT inertia and variability on mental well-being (sum score on the WEMWBS)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (inertia) | -1.07 (-4.22 – 2.07) | -0.02 | 0.503 | -3.44 (-6.47 – -0.40) | -0.08 | **0.026** | -0.37 (-4.19 – 3.45) | -0.01 | 0.850 | -2.79 (-7.22 – 1.63) | -0.06 | 0.216 |
| $PTQ_{EMA}$ (variability) | 0.20 (-0.08 – 0.48) | 0.06 | 0.162 | -0.14 (-0.42 – 0.14) | -0.04 | 0.330 | 0.09 (-0.26 – 0.45) | 0.02 | 0.615 | 0.18 (-0.23 – 0.59) | 0.04 | 0.400 |
| $PTQ_{EMA}$ (mean) | -0.30 (-0.45 – -0.15) | -0.18 | **<0.001** | -0.21 (-0.36 – -0.06) | -0.12 | **0.007** | -0.45 (-0.65 – -0.25) | -0.23 | **<0.001** | -0.20 (-0.44 – 0.03) | -0.10 | 0.086 |
| RRS-B at baseline | -0.62 (-0.81 – -0.43) | -0.26 | **<0.001** | 0.10 (-0.08 – 0.29) | 0.04 | 0.285 | -0.08 (-0.33 – 0.16) | -0.03 | 0.510 | -0.16 (-0.45 – 0.12) | -0.06 | 0.268 |
| PSWQ-A at baseline | -0.25 (-0.32 – -0.17) | -0.27 | **<0.001** | -0.06 (-0.13 – 0.01) | -0.06 | 0.120 | 0.04 (-0.06 – 0.13) | 0.04 | 0.441 | -0.05 (-0.15 – 0.06) | -0.04 | 0.418 |
| WEMWBS at baseline | | | | 0.64 (0.56 – 0.71) | 0.60 | **<0.001** | 0.47 (0.37 – 0.57) | 0.41 | **<0.001** | 0.38 (0.27 – 0.49) | 0.32 | **<0.001** |
| Condition (self-monitoring) | | | | -0.55 (-1.67 – 0.58) | -0.07 | 0.343 | 0.63 (-0.82 – 2.08) | 0.08 | 0.393 | 0.90 (-0.81 – 2.61) | 0.11 | 0.300 |
| Condition (self-Monitoring + EC) | | | | 0.16 (-0.90 – 1.21) | 0.02 | 0.769 | -0.04 (-1.39 – 1.31) | -0.01 | 0.953 | 0.85 (-0.71 – 2.42) | 0.10 | 0.285 |
| Observations | 665 | | | 574 | | | 554 | | | 501 | | |
| $R^2$ / $R^2$ adjusted | 0.293 / 0.288 | | | 0.475 / 0.467 | | | 0.283 / 0.273 | | | 0.182 / 0.168 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; *$R^2$ (adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table S4**

*Linear regressions testing the effects of RNT instability on depressive symptoms (sum score on the PHQ-9)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (instability) | -0.12 (-0.21 – -0.03) | -0.07 | **0.008** | -0.03 (-0.14 – 0.08) | -0.01 | 0.625 | 0.06 (-0.07 – 0.19) | 0.03 | 0.370 | 0.08 (-0.07 – 0.23) | 0.04 | 0.288 |
| $PTQ_{EMA}$ (mean) | 0.14 (0.09 – 0.18) | 0.17 | **<0.001** | 0.23 (0.18 – 0.29) | 0.26 | **<0.001** | 0.19 (0.13 – 0.26) | 0.20 | **<0.001** | 0.15 (0.07 – 0.23) | 0.14 | **<0.001** |
| RRS-B at baseline | 0.33 (0.25 – 0.40) | 0.27 | **<0.001** | 0.12 (0.02 – 0.2)1 | 0.08 | **0.014** | 0.16 (0.05 – 0.27) | 0.11 | **0.005** | 0.07 (-0.07 – 0.20) | 0.04 | 0.323 |
| PSWQ-A at baseline | 0.14 (0.11 – 0.16) | 0.29 | **<0.001** | 0.02 (-0.01 – 0.06) | 0.04 | 0.243 | -0.02 (-0.06 – 0.02) | -0.03 | 0.407 | 0.02 (-0.03 – 0.07) | 0.03 | 0.509 |
| PHQ-9 at baseline | | | | 0.41 (0.33 – 0.48) | 0.35 | **<0.001** | 0.41 (0.32 – 0.50) | 0.33 | **<0.001** | 0.36 (0.25 – 0.46) | 0.28 | **<0.001** |
| Condition (self-monitoring) | | | | 0.59 (0.02 – 1.15) | 0.15 | **0.042** | 0.50 (-0.17 – 1.16) | 0.12 | 0.143 | -0.00 (-0.80 – 0.79) | -0.00 | 0.998 |
| Condition (self-Monitoring + EC) | | | | 0.30 (-0.23 – 0.84) | 0.08 | 0.269 | 0.18 (-0.45 – 0.82) | 0.04 | 0.573 | 0.16 (-0.59 – 0.91) | 0.03 | 0.678 |
| Observations | 994 | | | 820 | | | 771 | | | 698 | | |
| $R^2$ / $R^2$ adjusted | 0.329 / 0.326 | | | 0.339 / 0.333 | | | 0.253 / 0.246 | | | 0.160 / 0.152 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table S5**

*Linear regressions testing the effects of RNT instability on generalized anxiety symptoms (sum score on the GAD-7)*

| | Baseline | | | One-month Follow-up | | | Three-month Follow-up | | | Twelve-month Follow-up | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (instability) | -0.02 (-0.11 – 0.06) | -0.01 | 0.585 | 0.07 (-0.02 – 0.17) | 0.04 | 0.130 | 0.14 (0.02 – 0.27) | 0.07 | **0.021** | -0.01 (-0.15 – 0.13) | -0.00 | 0.902 |
| $PTQ_{EMA}$ (mean) | 0.15 (0.11 – 0.19) | 0.18 | **<0.001** | 0.22 (0.17 – 0.27) | 0.25 | **<0.001** | 0.19 (0.13 – 0.26) | 0.21 | **<0.001** | 0.12 (0.05 – 0.20) | 0.13 | **0.001** |
| RRS-B at baseline | 0.25 (0.18 – 0.32) | 0.19 | **<0.001** | 0.05 (-0.03 – 0.13) | 0.04 | 0.241 | 0.10 (-0.01 – 0.21) | 0.07 | 0.064 | 0.07 (-0.05 – 0.20) | 0.05 | 0.262 |
| PSWQ-A at baseline | 0.23 (0.20 – 0.26) | 0.46 | **<0.001** | 0.11 (0.08 – 0.15) | 0.23 | **<0.001** | 0.07 (0.02 – 0.11) | 0.12 | **0.003** | 0.07 (0.02 – 0.12) | 0.12 | **0.010** |
| GAD-7 at baseline | | | | -0.06 (-0.56 – 0.43) | -0.02 | 0.803 | -0.05 (-0.68 – 0.59) | -0.01 | 0.885 | -0.08 (-0.83 – 0.66) | -0.02 | 0.825 |
| Condition (self-monitoring) | | | | 0.35 (0.28 – 0.42) | 0.34 | **<0.001** | 0.29 (0.20 – 0.38) | 0.26 | **<0.001** | 0.24 (0.13 – 0.34) | 0.21 | **<0.001** |
| Condition (self-Monitoring + EC) | | | | -0.16 (-0.63 – 0.30) | -0.04 | 0.497 | -0.12 (-0.73 – 0.48) | -0.03 | 0.688 | 0.21 (-0.49 – 0.91) | 0.05 | 0.555 |
| Observations | 994 | | | 820 | | | 774 | | | 695 | | |
| $R^2$ / $R^2$ adjusted | 0.463 / 0.460 | | | 0.477 / 0.473 | | | 0.284 / 0.277 | | | 0.170 / 0.162 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

**Table S6**

*Linear regressions testing the effects of RNT instability on mental well-being (sum score on the WEMWBS)*

| | **Baseline** | | | **One-month Follow-up** | | | **Three-month Follow-up** | | | **Twelve-month Follow-up** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* | *B (CI)* | *β* | *p* |
| $PTQ_{EMA}$ (instability) | 0.09 (-0.09 – 0.27) | 0.03 | 0.335 | -0.09 (-0.27 – 0.10) | -0.03 | 0.346 | -0.08 (-0.31 – 0.16) | -0.02 | 0.512 | 0.04 (-0.22 – 0.31) | 0.01 | 0.749 |
| $PTQ_{EMA}$ (mean) | -0.25 (-0.35 – -0.16) | -0.16 | **<0.001** | -0.21 (-0.30 – -0.12) | -0.13 | **<0.001** | -0.34 (-0.46 – -0.22) | -0.19 | **<0.001** | -0.20 (-0.33 – -0.06) | -0.11 | **0.005** |
| RRS-B at baseline | -0.55 (-0.71 – -0.40) | -0.23 | **<0.001** | 0.01 (-0.15 – 0.16) | 0.00 | 0.921 | -0.05 (-0.25 – 0.16) | -0.02 | 0.666 | -0.05 (-0.28 – 0.19) | -0.02 | 0.683 |
| PSWQ-A at baseline | -0.24 (-0.30 – -0.18) | -0.26 | **<0.001** | -0.02 (-0.08 – 0.04) | -0.02 | 0.472 | 0.03 (-0.04 – 0.11) | 0.03 | 0.415 | -0.03 (-0.12 – 0.06) | -0.03 | 0.493 |
| WEMWBS at baseline | | | | 0.62 (0.56 – 0.69) | 0.60 | **<0.001** | 0.48 (0.40 – 0.56) | 0.43 | **<0.001** | 0.40 (0.31 – 0.49) | 0.35 | **<0.001** |
| Condition (self-monitoring) | | | | -0.78 (-1.73 – 0.17) | -0.11 | 0.108 | 0.01 (-1.21 – 1.23) | 0.00 | 0.992 | 0.14 (-1.24 – 1.53) | 0.02 | 0.838 |
| Condition (self-Monitoring + EC) | | | | 0.11 (-0.79 – 1.01) | 0.01 | 0.811 | -0.24 (-1.40 – 0.93) | -0.03 | 0.692 | -0.17 (-1.48 – 1.14) | -0.02 | 0.799 |
| Observations | 994 | | | 823 | | | 775 | | | 698 | | |
| $R^2$ / $R^2$ adjusted | 0.261 / 0.258 | | | 0.448 / 0.443 | | | 0.270 / 0.263 | | | 0.181 / 0.173 | | |

*Note. B* (CI)= unstandardized regression coefficient (with 95% confidence interval), *β* = standardized regression coefficient, *p* = *p*-value; $R^2$ *(adjusted)* = (adjusted) coefficient of determination, self-monitoring = self-monitoring only app, self-monitoring + EC = self-monitoring + personalized emotional competence training self-help via app. Reference group for condition is self-monitoring + generic cognitive-behavioral therapy self-help via app.

# Appendix C:

## Supplementary Material *Study III*

*Heritability of Stable of Generalized Anxiety - a Longitudinal Twin Study in Young Adults*

Appendix C

## A. Univariate twin models of generalized anxiety

### Table S1

*Fit comparisons for univariate twin models of generalized anxiety*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| *Generalized anxiety wave 1* | | | | | | | |
| Saturated | - | 29171.34 | 8395 | 29191.34 | N/A | N/A | N/A |
| Saturated | ACE | 29181.31 | 8401 | 29189.31 | 9.97 | 6 | .13 |
| ACE | AE | 29181.31 | 8402 | 29187.31 | 0.00 | 1 | 1 |
| Saturated | **ADE** | **29177.37** | **8401** | **29185.37** | **6.04** | **6** | **.42** |
| ADE | AE | 29181.31 | 8402 | 29187.31 | 3.93 | 3.93 | <.05 |
| *Generalized anxiety wave 2* | | | | | | | |
| Saturated | - | 16449.24 | 4875 | 16469.24 | N/A | N/A | N/A |
| Saturated | ACE | 16455.82 | 4881 | 16463.82 | 6.58 | 6 | .36 |
| ACE | **AE** | **16455.82** | **4882** | **16461.82** | **0.00** | **1** | **1** |
| Saturated | ADE | 16455.74 | 4881 | 16463.74 | 6.50 | 6 | .37 |
| ADE | AE | 16455.82 | 4882 | 16461.82 | 0.08 | 1 | .78 |
| *Generalized anxiety wave 3* | | | | | | | |
| Saturated | - | 13787.01 | 4028 | 13807.01 | N/A | N/A | N/A |
| Saturated | ACE | 13797.17 | 4034 | 13805.17 | 10.17 | 6 | .12 |
| ACE | **AE** | **13797.65** | **4035** | **13803.65** | **0.47** | **1** | **.49** |
| Saturated | ADE | 13797.65 | 4034 | 13805.65 | 10.64 | 6 | .10 |
| ADE | AE | 13797.65 | 4035 | 13803.65 | 0.00 | 1 | 1 |
| *Generalized anxiety wave 4* | | | | | | | |
| Saturated | - | 12507.03 | 3638 | 12527.03 | N/A | N/A | N/A |
| Saturated | ACE | 12516.98 | 3644 | 12524.98 | 9.96 | 6 | .13 |
| ACE | **AE** | **12516.98** | **3645** | **12522.98** | **0.00** | **1** | **1** |
| Saturated | ADE | 12516.26 | 3644 | 12524.26 | 9.23 | 6 | .16 |
| ADE | AE | 12516.98 | 3645 | 12522.98 | 0.73 | 1 | .39 |
| *Generalized anxiety wave 5* | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Saturated | - | 13214.33 | 3863 | 13234.33 | N/A | N/A | N/A |
| Saturated | ACE | 13223.07 | 3869 | 13231.07 | 8.74 | 6 | .19 |
| ACE | **AE** | **13223.07** | **3870** | **13229.07** | **0.00** | **1** | **1** |
| Saturated | ADE | 13223.05 | 3869 | 13231.05 | 8.72 | 6 | .19 |
| ADE | **AE** | **13223.07** | **3870** | **13229.07** | **0.02** | **1** | **.89** |
| *Generalized anxiety wave 6* | | | | | | | |
| Saturated | - | 28144.65 | 8115 | 28164.65 | N/A | N/A | N/A |
| Saturated | ACE | 28151.64 | 8121 | 28159.64 | 6.99 | 6 | .32 |
| ACE | **AE** | **28151.64** | **8122** | **28157.64** | **0.00** | **1** | **1** |
| Saturated | ADE | 28150.61 | 8121 | 28158.61 | 5.96 | 6 | .43 |
| ADE | AE | 28151.64 | 8122 | 28157.64 | 1.02 | 1 | .31 |

*Note.* -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors. The best fitting genetic model is indicated in bold.

**Table S2**

*Twin correlations and parameter estimates with 95% confidence intervals for univariate twin models of generalized anxiety*

| | rMZ | rDZ | A | D | E |
|---|---|---|---|---|---|
| Generalised anxiety wave 1 | .41 (.36 - .45) | .15 (.11 - .19) | .22 (.04 - .39) | .19 (.01 - .39) | .59 (.55 - .63) |
| Generalised anxiety wave 2 | .44 (.38 - .50) | .22 (.15 - .28) | .45 (.40 - .59) | - | .55 (.50 - .60) |
| Generalised anxiety wave 3 | .38 (.30 - .45) | .20 (.13 - .28) | .39 (.35 - .43) | - | .61 (57 - .65) |
| Generalised anxiety wave 4 | .47 (.40 - .53) | .20 (.12 - .27) | .46 (.40 - .52) | - | .54 (.48 - .60) |
| Generalised anxiety wave 5 | .44 (.37 - .51) | .23 (.15 - .30) | .45 (.39 - .51) | - | .55 (.49 - .61) |
| Generalised anxiety wave 6 | .45 (.40 - .49) | .19 (.14 - .24) | .44 (.40 - .48) | - | .56 (.52 - .60) |

*Note.* rMZ = cross-twin correlations for monozygotic twins; rDZ = cross-twin correlations for dizygotic twins; A = additive genetic factors; D = dominance genetic factors; E = non-shared environmental factors; generalised anxiety wave 1 to 6 = square root transformed total score on the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted.

## B. Phenotypic dimensions of generalized anxiety – factor analyses

### Table S3

*Model fit statistics for exploratory factor analysis of generalized anxiety items*

| Number of factors | df | RMSEA (≤.05) | RMSEA 90% CI | TLI (≥.95) | BIC | SRMR (≤.08) | Cum. variance | Minimum item loading |
|---|---|---|---|---|---|---|---|---|
| *wave 1* | | | | | | | | |
| 1 | 35 | .124 | (.120 - .127) | .908 | 2924.9 | .04 | .62 | 10 |
| **2** | **26** | **.078** | **(.074 - .083)** | **.963** | **751.16** | **.02** | **.67** | **3** |
| 3 | 18 | .049 | (.044 - .054) | .986 | 120.34 | .01 | .69 | 1 |
| *wave 2* | | | | | | | | |
| 1 | 35 | .128 | (.123 - .133) | . 897 | 1726.61 | .05 | .60 | 10 |
| **2** | **26** | **.084** | **(.078 - .089)** | **.956** | **445.33** | **.02** | **.65** | **3** |
| 3 | 18 | .060 | (.053 - .067) | .978 | 92.41 | .01 | .68 | 1 |
| *wave 3* | | | | | | | | |
| 1 | 35 | .124 | (.118 - .129) | .909 | 1254.83 | .04 | .62 | 10 |
| **2** | **26** | **.083** | **(.077 - .090)** | **.958** | **327.35** | **.02** | **.66** | **4** |
| 3 | 18 | .047 | (.039 - .054) | .987 | -15.69 | .01 | .69 | 1 |
| *wave 4* | | | | | | | | |
| 1 | 35 | .124 | (.118 - .130) | .908 | 1140.56 | .04 | .62 | 10 |
| **2** | **26** | **.074** | **(.068 - .081)** | **.967** | **187.11** | **.02** | **.66** | **3** |
| 3 | 18 | .055 | (.047 - .063) | .982 | 14.6 | .01 | .69 | 0 |
| *wave 5* | | | | | | | | |
| 1 | 35 | .134 | (.129 - .140) | .888 | 1494.58 | .05 | .61 | 10 |
| **3** | **26** | **.075** | **(.069 - .081)** | **.965** | **222.18** | **.02** | **.66** | **3** |
| 3 | 18 | .052 | (.045 - .060) | .983 | 11.74 | .01 | .68 | 1 |
| *wave 6* | | | | | | | | |
| 1 | 35 | .143 | (.139 - .147) | .880 | 3871.57 | .05 | .62 | 10 |
| **2** | **26** | **.079** | **(.075 - .083)** | **.963** | **740.68** | **.02** | **.67** | **3** |
| 3 | 18 | .060 | (.055 - .065) | .979 | 235.93 | .01 | .69 | 0 |

*Note*. Generalized anxiety items = items of the Generalized Anxiety Disorder assessment, 10-item version; BIC = Bayesian information criterion; df = degrees of freedom; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residuals; TLI = Tucker–Lewis fit index. The cut off for good fit for each fit index is printed in the header. For BIC, the lowest BIC relative to the other models indicates the best fit. Cum (= cumulative) variance is defined as cumulative proportion of variance explained by all factors. Minimum item loading is defined as the minimum number of items loadings >.3 and greater than on any other factors. Factors were allowed to correlate using oblimin rotation. Best fitting and chosen models for each wave are indicated in bold.

**Table S4**

*Factor loadings for the two factor solutions of generalized anxiety items*

| Item | wave 1 | | wave 2 | | wave 3 | | wave 4 | | wave 5 | | wave 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F1 | F2 | F1 | F2 | F1 | F2 | F1 | F2 | F1 | F2 |
| I have felt moments of sudden terror, fear, or fright | .84 | .05 | .89 | -.06 | .90 | -.06 | .91 | -.09 | .90 | -.08 | .88 | -.02 |
| I have felt anxious, worried, or nervous | .73 | .16 | .83 | .07 | .70 | .21 | .87 | .01 | .81 | .08 | .80 | .03 |
| I have had thoughts of bad things happening, such as family tragedy, ill health, loss of a job, or accidents | .76 | .00 | .70 | .05 | .70 | .07 | .71 | .06 | .66 | .11 | .67 | .07 |
| I have felt a racing heart, sweaty, trouble breathing, faint, or shaky | .91 | -.10 | .89 | -.07 | .91 | -.09 | .84 | -.02 | .86 | -.06 | .91 | -.03 |
| I have felt tense muscles, felt on edge or restless, or had trouble relaxing or trouble sleeping | .70 | .11 | .73 | .05 | .70 | .10 | .77 | .05 | .77 | .02 | .76 | .03 |
| I have avoided, or did not approach or enter situations about which I worry | -.04 | .92 | -.05 | .90 | -.02 | .88 | -.02 | .90 | -.02 | .93 | -.03 | .87 |
| I have left situations early or participated only minimally due to worries | .03 | .87 | .02 | .85 | .00 | .88 | .00 | .91 | .01 | .88 | .03 | .95 |
| I have spent a lot of time making decisions, putting off making decisions, or preparing for situations, due to worries | .17 | .69 | .16 | .68 | .07 | .70 | .27 | .58 | .27 | .60 | .19 | .55 |
| I have sought reassurance from others due to worries | .41 | .33 | .41 | .27 | .27 | .42 | .52 | .18 | .48 | .23 | .43 | .13 |
| I have needed help to cope with anxiety (e.g., alcohol or medications, superstitious objects) | .58 | .21 | .59 | .15 | .52 | .21 | .58 | .14 | .54 | .18 | .51 | .24 |

*Note*. Generalized anxiety items = items of the Generalized Anxiety Disorder assessment; 10-item version; F1 = factor 1, somatic-distress dimension; F2 = factor 2, worry-avoidance dimension.

**Tabe S5**

*Confirmatory factor analyses testing the two factor-solutions derived by the exploratory analyses in the 30% test and full sample*

| Sample | RMSEA (≤ .05) | RMSEA (90% C) | TLI (≥ .95) | CFI (≥ 0.95) | SRMR (≤ .08) |
|---|---|---|---|---|---|
| *wave 1* | | | | | |
| 30% test | .038 | (.320, .440) | .998 | .998 | .026 |
| full | .041 | (.320, .440) | .997 | .998 | .026 |
| *wave 2* | | | | | |
| 30% test | .037 | (.029, .046) | .998 | .998 | .027 |
| full | .040 | (.036, .044) | .997 | .998 | .026 |
| *wave 3* | | | | | |
| 30% test | .048 | (.040, .057) | .997 | .997 | .035 |
| full | .044 | (.040, .049) | .997 | .998 | .028 |
| wave 3* | | | | | |
| 30% test | .043 | (.034, .51) | .997 | .998 | .030 |
| full | .044 | (.039, .48) | .997 | .998 | .027 |
| *wave 4* | | | | | |
| 30% test | .032 | (.021, .042) | .999 | .999 | .025 |
| full | .037 | (.032, .042) | .998 | .999 | .023 |
| *wave 5* | | | | | |
| 30% test | .039 | (.030, .49) | .997 | .999 | .028 |
| full | .043 | (.38, .48) | .997 | .998 | .026 |
| *wave 6* | | | | | |
| 30% test | .043 | (.038, .050) | .997 | .998 | .030 |
| full | .045 | (.041, .048) | .997 | .998 | .028 |

*Note*. RMSEA = root mean square error of approximation; SRMR = standardized root mean square residuals; TLI = Tucker–Lewis fit index; CFI = Comparative fit index. The cut off for good fit for each fit index is printed in the header; wave 3* test of the same factor structure that was derived for the other five waves.

## C. Twin models of the somatic-distress dimension

### Table S6

*Fit comparisons for univariate twin models of the somatic-distress dimension*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| *Somatic-distress dimension wave 1* | | | | | | | |
| Saturated | - | 26304.55 | 8391 | 26324.55 | N/A | N/A | N/A |
| Saturated | ACE | 26315.27 | 8397 | 26323.27 | 10.72 | 6 | .10 |
| ACE | AE | 26315.27 | 8398 | 26321.27 | 0.00 | 1 | 1 |
| Saturated | **ADE** | **26310.26** | **8397** | **26318.26** | **5.71** | **6** | **.46** |
| ADE | AE | 26315.27 | 8398 | 26321.27 | 5.01 | 1 | .03 |
| *Somatic-distress dimension wave 2* | | | | | | | |
| Saturated | - | 14788.82 | 4875 | 14808.82 | N/A | N/A | N/A |
| Saturated | ACE | 14796.03 | 4881 | 14804.03 | 7.22 | 6 | .30 |
| ACE | **AE** | **14796.03** | **4882** | **14802.03** | **0.00** | **1** | **1** |
| Saturated | ADE | 14796.01 | 4881 | 14804.01 | 7.19 | 6 | .30 |
| ADE | AE | 14796.03 | 4882 | 14802.03 | 0.02 | 1 | .88 |
| *Somatic-distress dimension wave 3* | | | | | | | |
| Saturated | - | 12350.33 | 4028 | 12370.33 | N/A | N/A | N/A |
| Saturated | ACE | 12361.39 | 4034 | 12369.39 | 11.05 | 6 | .09 |
| ACE | **AE** | **12361.45** | **4035** | **12367.45** | **0.07** | **1** | **.80** |
| Saturated | ADE | 12361.45 | 4034 | 12369.45 | 11.12 | 6 | .08 |
| ADE | AE | 12361.45 | 4035 | 12367.45 | 0.00 | 1 | 1 |
| *Somatic-distress dimension wave 4* | | | | | | | |
| Saturated | - | 11224.52 | 3638 | 11244.52 | N/A | N/A | N/A |
| Saturated | ACE | 11240.77 | 3644 | 11248.77 | 16.26 | 6 | .01 |
| ACE | **AE** | **11240.77** | **3645** | **11246.77** | **0.00** | **1** | **1** |
| Saturated | ADE | 11239.26 | 3644 | 11247.26 | 14.75 | 6 | .02 |
| ADE | AE | 11240.77 | 3645 | 11246.77 | 1.51 | 1 | .22 |
| *Somatic-distress dimension wave 5* | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Saturated | - | 11852.93 | 3863 | 11872.93 | N/A | N/A | N/A |
| Saturated | ACE | 11865.19 | 3869 | 11873.19 | 12.23 | 6 | .06 |
| ACE | **AE** | **11865.19** | **3870** | **11871.19** | **0.00** | **1** | **1** |
| Saturated | ADE | 11864.54 | 3869 | 11872.54 | 11.61 | 6 | .07 |
| ADE | AE | 11865.19 | 3870 | 11871.19 | 0.65 | 1 | .42 |
| *Somatic-distress dimension wave 6* | | | | | | | |
| Saturated | - | 25051.04 | 8073 | 25071.04 | N/A | N/A | N/A |
| Saturated | ACE | 25058.48 | 8079 | 25066.48 | 7.44 | 6 | .28 |
| ACE | AE | **25058.48** | **8080** | **25064.48** | **0.00** | **1** | **1** |
| Saturated | ADE | 25056.35 | 8079 | 25064.35 | 5.31 | 6 | .50 |
| ADE | AE | 25058.48 | 8080 | 25064.48 | 2.13 | 1 | 1.4 |

*Note.* -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors. The best fitting genetic model is indicated in bold.

**Table S7**

*Twin correlations and parameter estimates with 95% confidence intervals for univariate twin models of the somatic distress dimension*

| | rMZ | rDZ | A | D | E |
|---|---|---|---|---|---|
| Somatic-distress dimension wave 1 | .41 (.36 - .45) | .15 (.10 - .19) | .19 (.02 - .37) | .22 (.04 - .41) | .59 (.54 - .63) |
| Somatic-distress dimension wave 2 | .45 (.39 - .51) | .22 (.15 - .28) | .46 (.40 - .51) | - | .54 (.49 - .60) |
| Somatic-distress dimension wave 3 | .39 (.32 - .46) | .19 (.12 - .26) | .39 (.33 - .45) | - | .61 (.55 - .67) |
| Somatic-distress dimension wave 4 | .48 (.41 - .55) | .19 (.11 - .27) | .47 (.40 - .53) | - | .53 (.47 - .60) |
| Somatic-distress dimension wave 5 | .44 (.37 - .51) | .20 (.12 - .28) | .45 (.38 - .50) | - | .55 (.50 - .62) |
| Somatic-distress dimension wave 6 | .44 (.39 - .49) | .18 (.13 - .22) | .43 (.39 - .47) | - | .57 (.53 - .61) |

*Note.* rMZ = cross-twin correlations for monozygotic twins; rDZ = cross-twin correlations for dizygotic twins; A = additive genetic factors; D = dominance genetic factors; E = non-shared environmental factors; somatic-distress dimension wave 1 to 6 = square root transformed total score of the items loading onto the somatic-distress factor of the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted.

**Table S8**

*Fit comparisons for multivariate twin models of the somatic-distress dimension*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| Saturated | - | 86315.93 | 32748 | 86675.93 | N/A | N/A | N/A |
| Saturated | Constrained | 86474.65 | 32859 | 86612.65 | 158.72 | 111 | <.01 |
| *Cholesky Decomposition* | | | | | | | |
| Saturated | ACE | 86490.49 | 32859 | 86628.49 | 174.56 | 111 | <.001 |
| Saturated | AE | 86492.90 | 32880 | 86588.90 | 176.97 | 132 | <.01 |
| ACE | AE | 86492.90 | 32880 | 86588.90 | 2.41 | 21 | 1 |
| Saturated | ADE | 86484.14 | 32859 | 86622.14 | 168.21 | 111 | <.001 |
| ADE | **AE** | **86492.90** | **32880** | **86588.90** | **8.75** | **21** | **.99** |
| *Common pathway* | | | | | | | |
| Saturated | ACE | 86650.80 | 32896 | 86716.80 | 334.88 | 148 | <.001 |
| Saturated | AE | 86651.27 | 32903 | 86703.27 | 335.34 | 155 | <.001 |
| ACE | AE | 86651.27 | 32903 | 86703.27 | 0.46 | 7 | 1 |
| Saturated | ADE | 86645.96 | 32896 | 86711.96 | 330.03 | 148 | <.001 |
| ADE | **AE** | **86651.27** | **32903** | **86703.27** | **5.30** | **7** | **.62** |

*Note*. -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors; constrained = constrained model with equal means and variances across twins and zygosity groups as well as symmetric cross-twin cross-wave covariance matrices. The best fitting Cholesky and common pathway model is indicated in bold. The best fitting Cholesky and common pathway models are indicated in bold. Fit of the best fitting Cholesky and common pathway model was significantly worse than fit of the saturated model. However, this is common in twin studies with large sample sizes, where minimal variance deviations from the model's assumptions can be statistically significant (e.g., Waszczuk et al., 2016; Cheesman et al., 2018).

**Table S9**

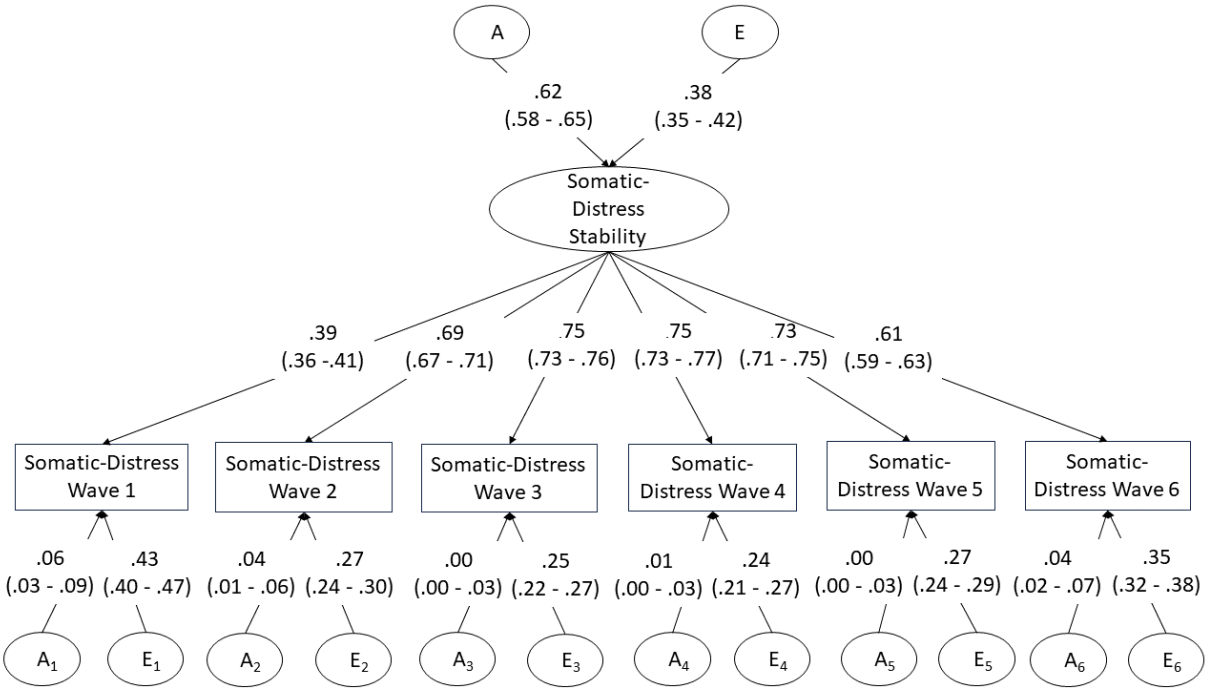
*Parameter estimates with 95% confidence intervals for Cholesky decomposition of the somatic-distress dimension*

| | w1 factors | | w2 factors | | w3 factors | | w4 factors | | w5 factors | | w6 factors | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $E_1$ | $A_2$ | $E_2$ | $A_3$ | $E_3$ | $A_4$ | $E_4$ | $A_5$ | $E_5$ | $A_6$ | $E_6$ |
| Somatic-distress dimension wave 1 | **.40** (.36-.43) | **.60** (.57-.64) | | | | | | | | | | |
| Somatic-distress dimension wave 2 | **.34** (.29-.40) | **.08** (.06 -.11) | **.11** (.06-.16) | **.47** (.43-.51) | | | | | | | | |
| Somatic-distress dimension wave 3 | **.37** (.32-.43) | **.08** (.06-.11) | .03 (.00-.07) | **.14** (.11-.18) | .02 (.00-.04) | **.36** (.33-.39) | | | | | | |
| Somatic-distress dimension wave 4 | **.38** (.32-.44) | **.08** (.05-.10) | **.04** (.01-.08) | **.09** (.07-.12) | .02 (.00-.06) | **.05** (.03-.07) | .02 (.00-.05) | **.33** (.30-.36) | | | | |
| Somatic-distress dimension wave 5 | **.37** (.32-.43) | **.07** (.05-.10) | **.05** (.01-.10) | **.07** (.05-.10) | .00 (.00-.04) | **.04** (.03-.06) | .01 (.00-.04) | **.03** (.02-.04) | .00 (.00-.03) | **.34** (.31-.36) | | |
| Somatic-distress dimension wave 6 | **.38** (.33-.43) | **.06** (.04-.08) | .02 (.00-.06) | **.05** (.03-.06] | .00 (.00-.06) | **.03** (.02-.04) | .04 (.00-.08) | **.02** (.01-.03) | .00 (.00-.06) | **.02** (.01-.03) | .00 (.00-.05) | **.38** (.35-.41) |

*Note.* A = additive genetic factors; E = non-shared environmental factors; somatic-distress dimension wave 1 to 6 = square root transformed total score of the items loading onto the somatic-distress factor of the Generalized Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted. Significant estimates are indicated in bold.

**Figure S1**

*Common pathway model of the somatic-distress dimension*




*Note*. A = additive genetic factors; E = non-shared environmental factors; somatic-distress wave 1 to 6 = square root transformed total score of the items loading onto the somatic-distress factor of the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6; generalised anxiety stability = latent stability of generalised anxiety. Parameter estimates presented in the figure are variance components. To obtain path coefficients, estimates should be square rooted.

## C. Twin models of the worry-avoidance dimension

### Table S10

*Fit comparisons for univariate twin models of the worry-avoidance dimension*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| *Worry-avoidance dimension wave 1* | | | | | | | |
| Saturated | - | 23219.81 | 8391 | 23239.81 | N/A | N/A | N/A |
| Saturated | ACE | 23227.86 | 8397 | 23235.86 | 8.05 | 6 | .23 |
| ACE | **AE** | **23227.86** | **8398** | **23233.86** | **0.00** | **1** | **1** |
| Saturated | ADE | 23225.55 | 8397 | 23233.55 | 5.74 | 6 | .45 |
| ADE | AE | 23227.86 | 8398 | 23233.86 | 2.32 | 1 | 1.3 |
| *Worry-avoidance dimension wave 2* | | | | | | | |
| Saturated | - | 13497.27 | 4875 | 13517.27 | N/A | N/A | N/A |
| Saturated | ACE | 13502.09 | 4881 | 13510.09 | 4.81 | 6 | .57 |
| ACE | **AE** | **13502.09** | **4882** | **13508.09** | **0.00** | **1** | **1** |
| Saturated | ADE | 13502.00 | 4881 | 13510.00 | 4.73 | 6 | .58 |
| ADE | AE | 13502.09 | 4882 | 13508.09 | 0.08 | 1 | .77 |
| *Worry-avoidance dimension wave 3* | | | | | | | |
| Saturated | - | 11215.01 | 4028 | 11235.01 | N/A | N/A | N/A |
| Saturated | ACE | 11221.95 | 4034 | 11229.95 | 6.94 | 6 | .33 |
| ACE | **AE** | **11223.13** | **4035** | **11229.13** | **1.18** | **1** | **2.78** |
| Saturated | ADE | 11223.13 | 4034 | 11231.13 | 8.12 | 6 | .23 |
| ADE | AE | 11223.13 | 4035 | 11229.13 | 0.00 | 1 | 1 |
| *Worry-avoidance dimension wave 4* | | | | | | | |
| Saturated | - | 10171.40 | 3638 | 10191.40 | N/A | N/A | N/A |
| Saturated | ACE | 10176.47 | 3644 | 10184.47 | 5.07 | 6 | .53 |
| ACE | **AE** | **10176.47** | **3645** | **10182.47** | **0.00** | **1** | **1** |
| Saturated | ADE | 10176.44 | 3644 | 10184.44 | 5.03 | 6 | .54 |
| ADE | AE | 10176.47 | 3645 | 10182.47 | 0.03 | 1 | .85 |
| *Worry-avoidance dimension wave 5* | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Saturated | - | 10703.92 | 3863 | 10723.92 | N/A | N/A | N/A |
| Saturated | ACE | 10706.75 | 3869 | 10714.75 | 2.84 | 6 | .83 |
| ACE | **AE** | **10709.65** | **3870** | **10715.65** | **2.90** | **1** | **.09** |
| Saturated | ADE | 10709.65 | 3869 | 10717.65 | 5.73 | 6 | .45 |
| ADE | AE | 10709.65 | 3870 | 10715.65 | 0.00 | 1 | 1 |
| *Worry-avoidance dimension wave 6* | | | | | | | |
| Saturated | - | 22734.15 | 8095 | 22754.15 | N/A | N/A | N/A |
| Saturated | ACE | 22738.14 | 8101 | 22746.14 | 3.99 | 6 | .68 |
| ACE | **AE** | **22738.14** | **8102** | **22744.14** | **0.00** | **1** | **1** |
| Saturated | ADE | 22738.09 | 8101 | 22746.09 | 3.94 | 6 | .68 |
| ADE | AE | 22738.14 | 8102 | 22744.14 | 0.05 | 1 | .83 |

*Note.* -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors. The best fitting genetic model is indicated in bold.

**Table S11**

*Twin correlations and parameter estimates with 95% confidence intervals for univariate twin models of the worry-avoidance dimension*

| | rMZ | rDZ | A | E |
|---|---|---|---|---|
| Worry-avoidance dimension wave 1 | .31 (.26 - .35) | .11 (.07 - .16) | .29 (.25 - .33) | .71 (.67 - .75) |
| Worry-avoidance dimension wave 2 | .33 (.26 - .40) | .15 (.09 - .22) | .33 (.27 - .39) | .67 (.61 - .83) |
| Worry-avoidance dimension wave 3 | .28 (.20 - .35) | .17 (.10 - .24) | .29 (.22 - .35) | .71 (.65 - .78) |
| Worry-avoidance dimension wave 4 | .32 (.23 - .39) | .15 (.07 - .22) | .31 (.24 - .38) | .69 (.62 - .76) |
| Worry-avoidance dimension wave 5 | .34 (.26 - .41) | .25 (.17 - .32) | .37 (.31 - .43) | .63 (.57 - .69) |
| Worry-avoidance dimension wave 6 | .35 (.30- .40) | .16 (.12 - .21) | .35 (.31 - .49) | .65 (.60 - .69) |

*Note.* rMZ = cross-twin correlations for monozygotic twins; rDZ = cross-twin correlations for dizygotic twins; A = additive genetic factors; D = dominance genetic factors; E = non-shared environmental factors; worry-avoidance dimension wave 1 to 6 = square root transformed total score of the items loading onto the worry-avoidance factor of the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted.

**Table S12**

*Fit comparisons for multivariate twin models of the worry-avoidance dimension*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| Saturated | - | 81045.85 | 32770 | 81405.85 | N/A | N/A | N/A |
| Saturated | Constrained | 81161.70 | 32881 | 81299.70 | 115.85 | 111 | .36 |
| *Cholesky Decomposition* | | | | | | | |
| Saturated | ACE | 81176.68 | 32881 | 81314.68 | 130.82 | 111 | .10 |
| Saturated | AE | 81180.33 | 32902 | 81276.33 | 134.47 | 132 | .42 |
| ACE | AE | 81180.33 | 32902 | 81276.33 | 3.65 | 21 | 1 |
| Saturated | ADE | 81177.09 | 32881 | 81315.09 | 31.23 | 111 | .09 |
| ADE | **AE** | **81180.33** | **32902** | **81276.33** | **3.24** | **21** | **1** |
| *Common pathway* | | | | | | | |
| Saturated | ACE | 81298.23 | 32918 | 81364.23 | 252.37 | 148 | <.001 |
| Saturated | AE | 81299.74 | 32925 | 81351.74 | 253.89 | 155 | <.001 |
| ACE | AE | 81299.74 | 32925 | 81351.74 | 1.52 | 7 | .98 |
| Saturated | ADE | 81296.63 | 32918 | 81362.63 | 250.78 | 148 | <.001 |
| ADE | **AE** | **81299.74** | **32925** | **81351.74** | **3.12** | **7** | **.87** |

*Note*. -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors; constrained = constrained model with equal means and variances across twins and zygosity groups as well as symmetric cross-twin cross-wave covariance matrices. The best fitting Cholesky and common pathway model is indicated in bold. The best fitting common pathway models are indicated in bold. Fit of the best fitting Cholesky and common pathway model was significantly worse than fit of the saturated model. However, this is common in twin studies with large sample sizes, where minimal variance deviations from the model's assumptions can be statistically significant (e.g., Waszczuk et al., 2016; Cheesman et al., 2018).

**Table S13**

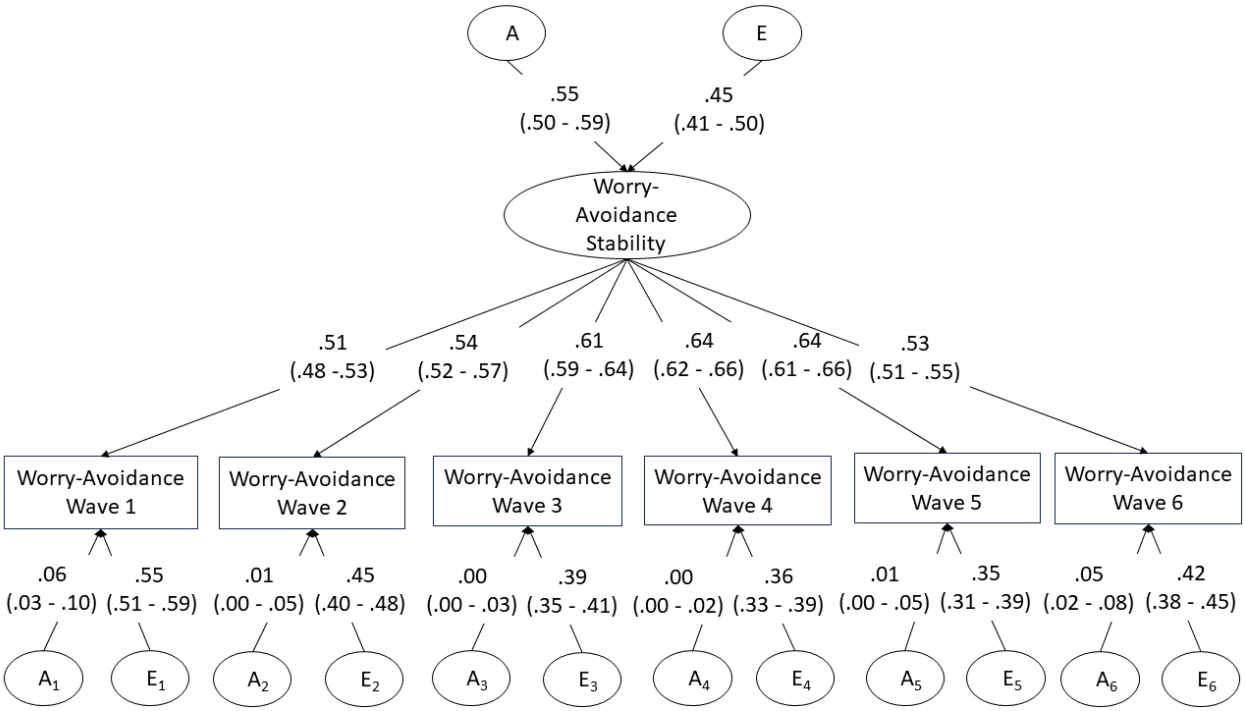
*Parameter estimates with 95% confidence intervals for Cholesky decomposition of the worry-avoidance dimension*

| | w1 factors | | w2 factors | | w3 factors | | w4 factors | | w5 factors | | w6 factors | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $E_1$ | $A_2$ | $E_2$ | $A_3$ | $E_3$ | $A_4$ | $E_4$ | $A_5$ | $E_5$ | $A_6$ | $E_6$ |
| Worry-avoidance dimension wave 1 | **.29** (.25-.23) | **.71** (.67-.75) | | | | | | | | | | |
| Worry-avoidance dimension wave 2 | **.24** (.18-.30) | **.06** (.04-.08) | **.09** (.03-.14) | **.61** (.57-.67) | | | | | | | | |
| Worry-avoidance dimension wave 3 | **.24** (.18-.30) | **.06** (.04-.09) | **.07** (.02-.12) | **.09** (.07-.12) | .00 (.00-.03) | **.54** (.50-.57) | | | | | | |
| Worry-avoidance dimension wave 4 | **.28** (.22-.34) | **.05** (.03-.07) | .02 (.00-.06) | **.08** (.06-.11) | .00 (.00-.04) | **.07** (.05-.09) | .01 (.00-.04) | **.49** (.45-.52) | | | | |
| Worry-avoidance dimension wave 5 | **.25** (.19-.31) | **.06** (.04-.08) | **.07** (.02-.13) | **.06** (.04-.08) | .00 (.00-.08) | **.05** (.04-.07) | .03 (.00-.08) | **.05** (.03-.07) | .00 (.00-.06) | **.43** (.39-.67) | | |
| Worry-avoidance dimension wave 6 | **.25** (.20-.31) | **.06** (.04-.08) | .03 (.00-.09) | **.04** (.02-.05) | .01 (.00-.01) | **.03** (.02-.05) | .06 (.00-.11) | **.02** (.01-.04) | .00 (.00-.08) | **.02** (.01-.03) | .00 (.00-.06) | **.48** (.44-.51) |

*Note*. A = additive genetic factors; E = non-shared environmental factors; worry-avoidance dimension wave 1 to 6 = square root transformed total score of the items loading onto the worry-avoidance factor of the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6. Parameter estimates presented in the table are variance components. To obtain path coefficients, estimates should be square rooted. Significant estimates are indicated in bold.

**Figure S2**

*Common pathway model of the worry-avoidance dimension*




*Note*. A = additive genetic factors; E = non-shared environmental factors; worry-avoidance wave 1 to 6 = square root transformed total score of the items loading onto the worry-avoidance factor of the Generalised Anxiety Disorder assessment, 10-item version, wave 1 to 6; generalised anxiety stability = latent stability of generalised anxiety. Parameter estimates presented in the figure are variance components. To obtain path coefficients, estimates should be square rooted.

**Table S14**

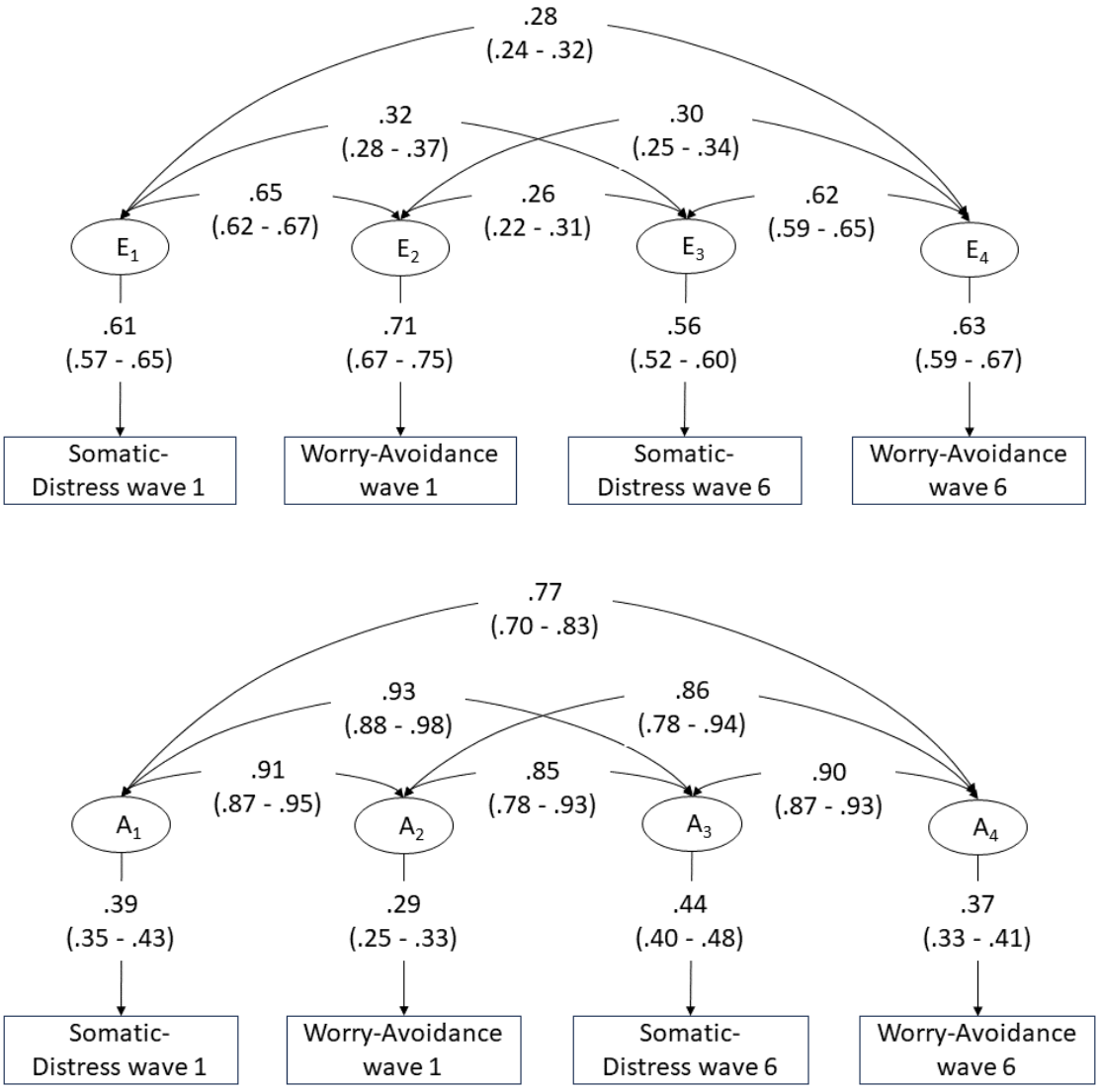
*Fit comparisons for multivariate twin models of somatic-distress and worry-avoidance dimension*

| Base Model | Comparison Model | -2LL | df | AIC | Δ -2LL | Δ df | *p* |
|---|---|---|---|---|---|---|---|
| Saturated | - | 82347.71 | 32902 | 82523.71 | N/A | N/A | N/A |
| Saturated | Constrained | 82380.90 | 32932 | 82496.90 | 3.19 | 30 | .31 |
| *Cholesky decomposition (correlated factor model)* | | | | | | | |
| Saturated | ACE | 82409.84 | 32956 | 82477.84 | 62.13 | 54 | .21 |
| Saturated | **AE** | **82410.90** | **32966** | **82458.90** | **63.18** | **64** | **.51** |
| ACE | AE | 82410.90 | 32966 | 82458.90 | 1.054 | 10 | 1 |
| Saturated | ADE | 82401.65 | 32956 | 82469.65 | 53.93 | 54 | .48 |
| ADE | AE | 82410.90 | 32966 | 82458.90 | 9.25 | 10 | .51 |

*Note*. -2LL = minus twice the log likelihood; df = degrees of freedom; AIC = Akaike's information criterion; A = additive genetic factors; C= shared environmental factors; E = non-shared environmental factors; D = dominance genetic factors. The best fitting Cholesky (correlated factor) model is indicated in bold.

**Figure S3**

*Correlated factor solution of somatic-distress and worry-avoidance dimension*




*Note*. A = additive genetic factors; E = non-shared environmental factors; worry-avoidance wave 1 and 6 = square root transformed total score of the items loading onto the worry-avoidance factor of the Generalized Anxiety Disorder assessment, 10-item version, wave 1 and 6; somatic-distress wave 1 and 6 = square root transformed total score of the items loading onto the somatic-distress factor of the Generalized Anxiety Disorder assessment, 10-item version, wave 1 and 6. For reasons of clarity, the correlated factor solution was estimated based on data from wave 1 and 6 only.

# Appendix D:

## Supplementary Material *Study IV*

*Can an Intervention Designed to Reduce Repetitive Negative Thinking Alter the Response to a Psychosocial Stressor? A Randomized Controlled Study*

## A. Intervention structure and contents

The intervention was designed to reduce repetitive negative thinking (RNT) and was administered via a smartphone app over the course of 10 days. The intervention consisted of the following modules (for an overview see Table 1).

**Table S1**

***Overview of structure and contents of the RNT-focused intervention.***

| Day | Module | Content | Modality |
|---|---|---|---|
| 1 | Psychoeducation on RNT | Psychoeducation, reflection of personal triggers for RNT | Video, explanatory text, multiple choice and open questions |
| 2 | Addressing RNT as a mental habit | Setting priorities, opposite action | Explanatory text, multiple choice and open questions |
| 3-4 | Training incompatible processing modes | Concrete thinking | Video, audio, multiple choice and open questions |
| 5-6 | | Self-compassion | Video, audio, multiple choice and open questions |
| 7-8 | | Mindfulness | Video, audio, multiple choice and open questions |
| 9 | Reflection and personalization | Reflection | Explanatory text, multiple choice and open questions |
| 10 | | Further training of chosen strategy | Video, audio, multiple choice and open questions |

*Note*. RNT = Repetitive negative thinking.

***Psychoeducation on RNT (day 1)***

*Day 1* started with *psychoeducation on RNT*. Participants watched a video explaining how RNT can affect mental health by becoming a mental habit that is automatically triggered by certain circumstances or situations. Following the video, participants could select their personal triggers or warning signs for RNT from a list of options, including situations (e.g., being criticized), bodily reactions (e.g., feeling tense in the shoulders) as well as times and places (e.g., after waking up). Next to the suggested options, participants could also add different personal triggers in free text fields. Participants' personal triggers and warning signs for RNT were then saved in the app so that participants could look at them at any time during the intervention.

***Addressing RNT as a mental habit (day 2)***

*Day 2* comprised exercises training simple strategies designed to *address and break RNT as a mental habit*. As stressful situations with many unfinished tasks frequently trigger habitual RNT, participants first learned strategies on how to set priorities and tackle stressful situations step by step instead of habitually engaging in RNT. After that, participants completed an exercise designed to address habitual RNT associated with negative emotions by engaging in *opposite actions*, which could be facial expressions, bodily postures or behaviors opposite to the negative emotion.

***Training processing modes that are incompatible with RNT (day 3-8)***

*Day 3-8* comprised exercises training processing modes that are incompatible with RNT, namely, *concrete thinking* (*day 3-4*), *self-compassion* (*day 5-6)* and *mindfulness* (*day 7-8*).

On *day 3* participants first watched a video explaining how concrete thinking about specific details, perceptions, and concrete solutions of a problem is different from abstract RNT about its potential causes, meanings or consequences. Following this, participants were instructed to compare how they felt when they thought abstractly about a fictive negative event to what effects concrete thinking about the same scenario had on them. On *day 4*, participants were guided to think concretely about a distressing situation or problem, which they had experienced themselves.

*Day 5* started with a video explaining how self-compassion is different from self-criticism that is characteristic of RNT and were then instructed to compare the effects that critical vs. kind self-talk had on them. On *day 6*, participants were guided to think in a self-compassioned way about a situation in which they felt like they had failed.

On *day 7* and *8* participants were guided through several mindfulness exercises to train a further state that is incompatible with being caught up in repetitive, negative thought cycles. Exercises included active breathing, being present in the here and now, progressive muscle relaxation and body scan.

***Reflection and personalization (day 9-10)***

On *day 9* participants were instructed to reflect on which of the strategies that they learned during the intervention were most helpful for reducing RNT. On *day 10,* participants could select to further train either *concrete thinking*, *self-compassion* or *mindfulness*, depending on which of these strategies they found most useful.

***Transfer to everyday life***

Throughout the intervention, participants could make if-then-plans to use one of the strategies they learned when experiencing triggers of RNT in a designated section in the app. These plans were structured as follows "*If* I will experience trigger X, *then* I will use strategy Y." The if-then-plans were saved in the app so that participants could look at them at any time during the intervention.

**B. Reasons for exclusions after completed screening**

A total of 64 participants who had completed the eligibility screening did not meet the inclusion criteria for the study. Reasons for exclusions were as follows. Please note that some participants met multiple exclusion criteria.

- Excluded based on too low scores on the trait RNT measure: $n = 31$

- Excluded due to too high scores on the depressive symptom measure: $n = 17$

- Excluded based on age*:* $n = 8$

- Excluded based on acute or chronic medical condition: $n = 4$

- Excluded due to regular nicotine consumption: $n = 8$

- Excluded based on psychological treatment at the time of the study: $n = 4$

- Excluded based on participation in an earlier study testing a similar app-based intervention: $n = 1$

**C. Descriptive statistics for negative affect before and after stressor**

Table S2 shows mean, standard deviation, range and skewness for raw and log-transformed sum scores on the Negative Affect Subscale of the Positive and Negative Affect Schedule – Short Form during the lab session.

**Table S2**

***Descriptive Statistics for negative affect by time point***

| Variable, timing | Transformation | *M* | *SD* | *Range* | *Skewness* |
|---|---|---|---|---|---|
| negative affect, -20 | raw | 8.18 | 2.40 | 5 - 15 | 0.91 |
| | log-transformed | 2.06 | 0.28 | 1.61 - 2.71 | 0.35 |
| negative affect, - 1 | raw | 7.37 | 2.51 | 5 - 20 | 2.19 |
| | log-transformed | 1.95 | 0.29 | 1.61 - 3 | 0.95 |
| negative affect, +1 | raw | 12.25 | 4.30 | 5 - 25 | 0.49 |
| | log-transformed | 2.44 | 0.36 | 1.61 - 3.22 | -0.16 |
| negative affect, +10 | raw | 8.42 | 3.24 | 5 - 20 | 1.12 |
| | log-transformed | 2.07 | 0.35 | 1.61 - 3 | 0.47 |
| negative affect, +20 | raw | 7.71 | 2.84 | 5 - 17 | 1.26 |
| | log-transformed | 1.98 | 0.33 | 1.61 - 2.83 | 0.62 |
| negative affect, +30 | raw | 6.85 | 2.26 | 5 - 16 | 1.67 |
| | log-transformed | 1.88 | 0.29 | 1.61 - 2.77 | 0.94 |
| negative affect, +45 | raw | 6.34 | 1.98 | 5 - 16 | 2.73 |
| | log-transformed | 1.81 | 0.25 | 1.61 - 2.77 | 1.57 |

*Note*. Negative affect, -20 – negative affect, +45 = sum score on the Negative Affect Subscale of the Positive and Negative Affect Schedule – Short Form 20 minutes pre to 45 minutes post stressor. M = mean, SD = Standard deviation, Range = minimum to maximum score observed.

## D. Detailed documentation hypothalamic–pituitary–adrenal axis stress response analyses

### *Missingness in cortisol data*

Of the final study sample ($N = 79$), $n = 6$ participants had missing cortisol data at critical time points and thus their data could not be used for analyzing hypothalamic–pituitary–adrenal (HPA) axis stress responses. Reasons for missingness in cortisol data were as follows. One participant in the control condition had missing data due to missing annotations of sample time point. Two participants in the control and three participants in the intervention condition had samples with insufficient saliva volume. In three cases, participants had missing cortisol data due to insufficient saliva volume at less critical time points, which could be replaced as follows. For one participant in the control condition, a missing cortisol value 1 minute pre stressor (baseline for all analyses) was replaced with the cortisol value 20 minutes pre-stressor. For two participants in the intervention condition, missing cortisol values 45 minutes post-stressor were

replaced with cortisol values 30 minutes post-stressor as the cortisol concentration already had started to decrease.

***Outliers in cortisol data***

Of the remaining 73 participants, one participant in the intervention and one participant in the control condition were excluded based on outliers (+ 3 standard deviations above mean) in cortisol values at one or more of the seven time points in accordance with our preregistered strategy (https://osf.io/bzrsh).

Due to missingness and exclusions based on outliers, the sample for analyzing maximal increase in cortisol comprised $n = 71$ ($n = 37$ intervention, $n = 34$ control) and the sample for analyzing cortisol recovery comprised $n = 70$ participants ($n = 37$ intervention, $n = 33$ control).

***Transformations***

As cortisol data at neither of the seven time points was normally distributed, cortisol variables were log-transformed for further analysis in line with our preregistered procedure (https://osf.io/bzrsh).

***Correlation between RNT post-stress exposure and HPA axis stress response***

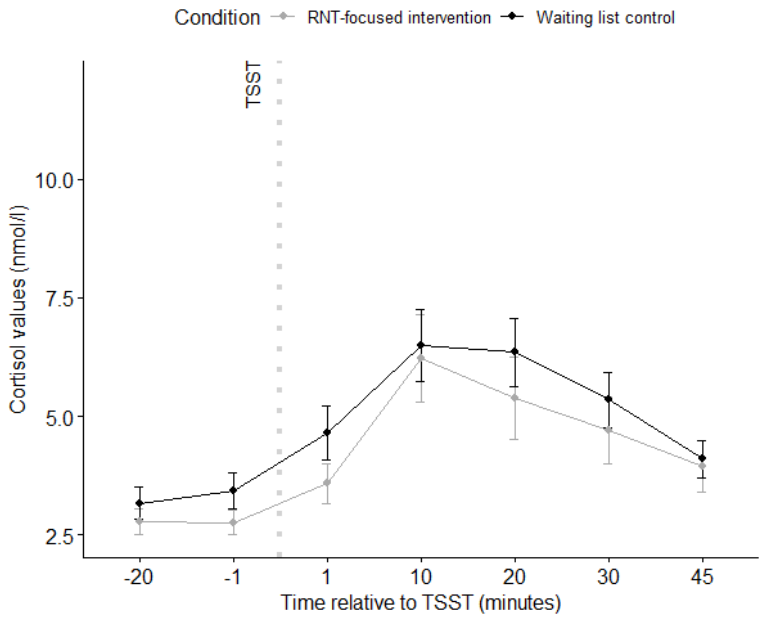
RNT post-stressor did not significantly correlate with maximal increase in cortisol, $r = -.15$, $p = .23$, and did not significantly predict cortisol recovery when controlling for baseline cortisol in the overall sample, $\beta = -0.07$, $p = .51$. Consistent with these results, analyses in the sperate conditions showed no significant associations between RNT post-stressor and HPA axis stress responses. RNT post-stressor neither significantly correlated with maximal increases in cortisol in the control, $r = -.06$, $p = .73$, nor in the intervention group, $r = -.25$, $p = .13$. Similarly, RNT post-stressor neither significantly predicted cortisol recovery when controlling for baseline cortisol in the control group, $\beta = -0.04$, $p = .81$, nor in the intervention group, $\beta = -0.15$, $p = .30$.

***Graphical depiction of HPA axis stress response by condition***

*Figure S1* depicts cortisol concentrations by condition and time point relative to the Trier Social Stress Test (TSST).

**Figure S1**

*Mean raw cortisol values with standard error bars before and after the TSST by condition*




*Note*. TSST = Trier Social Stress Test, nmol/l = Nanomoles per liter.

## E. Detailed documentation of autonomic nervous system stress responses analyses

### *Missingness in α amylase data*

Of the final study sample ($N$ = 79), $n$ = 5 participants had missing α amylase data at critical time points and thus their data could not be used for analyzing the autonomic nervous system (ANS) stress response. Reasons for missingness in α amylase data were as follows. One participant in the control condition had missing data due to missing annotations of sample time point. Two participants in the control and two participants in the intervention condition had samples with insufficient saliva volume so that α amylase concentrations could not be determined for any time point. In two other cases, participants had missing α-amylase data due to insufficient saliva volume at time points less critical for the analysis of the ANS stress response; therefore, their data could still be included. Due to missingness, the sample for analyzing the ANS stress response comprised $n$ = 74 ($n$ = 39 intervention, $n$ = 35 control) participants.

### *Outliers in in α amylase data*

There were no outliers in α amylase values.

### *Transformations*

A amylase values were not normally distributed at any of the time points and therefore, α amylase variables were log-transformed for further analysis.

### *Index computation*

The α amylase stress response is characterized by a rapid increase and early decline, unlike the cortisol stress response, which typically has a later start and longer duration. Accordingly, the computation of indices for the ANS stress response differed slightly from the computation of indices for the HPA axis stress response. As an index for the ANS stress response, we computed the maximal increase in α amylase by subtracting baseline (-1 minute pre-stressor) from peak α amylase value (either measured at +1, +10, or +20 minutes post-stressor) for each participant.

### *Correlation between RNT post-stress exposure and ANS stress response*

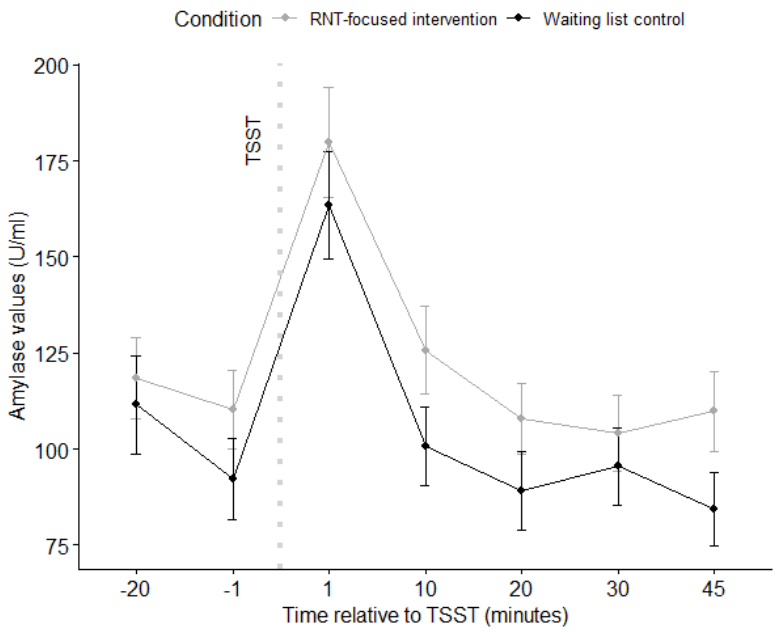
There was no significant correlation between RNT post-stressor and maximal increase in α amylase, $r$ = .-.003, $p$ = .98. Results for analyses testing this association separately in the single conditions were similar. RNT post-stressor did neither significantly correlate with maximal increase in α amylase in the control, $r$ = .01, $p$ = .96, nor in the intervention condition, $r$ = -.13, $p$ = .42.

### *Graphical depiction of ANS stress response by condition*

*Figure S2* depicts α amylase concentrations by condition and time point relative to the TSST.

**Figure S2**

*Mean raw α amylase values with standard error bars before and after the TSST by condition.*




*Note*. TSST = Trier Social Stress Test, U/ml = Units per milliliter.

# Appendix E:

## Supplementary Material *Study V*

*Can an Intervention Designed to Reduce Repetitive Negative Thinking Alter the Response to a Psychosocial Stressor? A Randomized Controlled Study*

Appendix E

## A. Effects on Diagnoses at Post-Intervention

### Table S1

*Logistic Regressions Predicting Probabilities for Diagnoses of Depression, Generalized Anxiety Disorder, and Social Anxiety Disorder at Post-Intervention*

| | **PHQ-9 Diagnosis** | | **GAD-7 Diagnosis** | | **SIAS Diagnosis** | |
|---|---|---|---|---|---|---|
| *Predictors* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* |
| Condition [full RNT-focused intervention] | 0.88<br>0.26 – 2.76 | .830 | 0.45<br>0.10 – 1.58 | .245 | 0.71<br>0.30 – 1.60 | .416 |
| Condition [concreteness training intervention] | 1.94<br>0.74 – 5.26 | .179 | 1.02<br>0.35 – 2.88 | .967 | 1.51<br>0.74 – 3.11 | .254 |
| Observations | 249 | | 249 | | 249 | |
| $R^2$ Tjur | .011 | | .007 | | .014 | |

*Note*. PHQ-9 diagnosis = total scale score on the Patient Health Questionnaire-9 > 9, GAD-7 diagnosis = total scale score on the Generalized Anxiety Disorder-7 Questionnaire > 9, SIAS diagnosis = total scale score on the Social Interaction Anxiety Scale > 35, $R^2$ Tjur = coefficient of determination by Tjur. The models were estimated based on the completer sample.

## B. Effects at Follow-Up

***Table S2***

*Effects at Follow-Up: Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ IV), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| **Outcome** | **IDS** | | **GADQ IV** | | **SPIN** | | **RRS** | | **PSWQ** | | **PTQ** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* |
| Condition [full RNT-focused intervention] | 0.74<br>-1.43 – 2.91 | .503 | -0.07<br>-0.69 – 0.55 | .834 | -0.71<br>-3.23 – 1.81 | .579 | 0.53<br>-1.73 – 2.80 | .645 | -0.42<br>-2.68 – 1.84 | .717 | -0.75<br>-3.18 – 1.68 | .547 |
| Condition [concreteness training intervention] | 1.54<br>-0.63 – 3.71 | .164 | 0.35<br>-0.27 – 0.97 | .271 | -0.46<br>-2.99 – 2.06 | .719 | 1.63<br>-0.64 – 3.90 | .160 | -0.32<br>-2.58 – 1.94 | .782 | 0.13<br>-2.30 – 2.57 | .915 |
| Time [post-intervention] | -1.00<br>-2.64 – 0.64 | .231 | **-0.92**<br>**-1.33 – -0.51** | **<.001** | 0.17<br>-1.47 – 1.81 | .839 | -1.04<br>-2.81 – 0.72 | .247 | **-1.50**<br>**-2.95 – -0.05** | **.043** | **-3.81**<br>**-5.53 – -2.09** | **<.001** |
| Time [follow-up] | -0.71<br>-2.55 – 1.13 | .449 | **-0.67**<br>**-1.13 – -0.20** | **.005** | 0.47<br>-1.37 – 2.31 | .615 | **-2.11**<br>**-4.08 – -0.13** | **.037** | -1.53<br>-3.16 – 0.10 | .066 | **-3.55**<br>**-5.48 – -1.62** | **<.001** |
| Condition [full RNT-focused intervention] * time [post-intervention] | -1.61<br>-4.10 – 0.89 | .206 | 0.21<br>-0.42 – 0.85 | .512 | -1.31<br>-3.82 – 1.21 | .308 | -1.73<br>-4.42 – 0.96 | .208 | -0.73<br>-2.96 – 1.50 | .520 | 0.64<br>-1.99 – 3.26 | .635 |
| Condition [concreteness training intervention] * time [post-intervention] | -0.15<br>-2.60 – 2.31 | .907 | 0.18<br>-0.44 – 0.80 | .571 | 1.48<br>-0.99 – 3.94 | .240 | -1.40<br>-4.04 – 1.25 | .300 | 0.52<br>-1.67 – 2.70 | .643 | 1.56<br>-1.02 – 4.14 | .236 |
| Condition [full RNT-focused intervention] * time [follow-up] | -0.49<br>-3.26 – 2.28 | .730 | -0.17<br>-0.88 – 0.53 | .635 | 0.07<br>-2.72 – 2.87 | .960 | -0.47<br>-3.46 – 2.51 | .756 | -1.22<br>-3.70 – 1.26 | .334 | 0.00<br>-2.92 – 2.93 | .998 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Condition [concreteness training intervention] *time [follow-up] | 1.22<br>-1.69 – 4.13 | .413 | -0.32<br>-1.06 – 0.42 | .397 | 1.05<br>-1.89 – 3.98 | .485 | -0.62<br>-3.75 – 2.51 | .699 | 0.20<br>-2.40 – 2.80 | .882 | 0.02<br>-3.04 – 3.08 | .990 |
| **Random Effects** | | | | | | | | | | | | |
| $\sigma^2$/ $\tau_{00}$ | 36.49/ 37.42 | | 2.33/ 3.79 | | 36.51/ 64.18 | | 42.99/ 38.59 | | 28.68/ 52.25 | | 40.42/ 53.34 | |
| *ICC*/ *N* (participants) | 0.51/ 364 | | 0.62/ 365 | | 0.64/ 365 | | 0.47/ 356 | | 0.65/365 | | 0.57/365 | |
| Observations | 783 | | 788 | | 788 | | 788 | | 788 | | 788 | |
| Marginal/ Conditional $R^2$ | .016 / .514 | | .032 / .631 | | .006 / .640 | | .020 / .483 | | .011 / .650 | | .031 / .582 | |

*Note*. Outcomes are total scale scores on the respective measure. The models were estimated based on the intention-to-treat sample. Reference level for condition is the waitlist control condition and reference level for time is baseline. $\sigma^2$= within-participant variability, $\tau_{00}$ = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional $R^2$ = Proportion of variance explained by fixed/ by fixed and random effects.

**Table S3**

*Effects at Follow-Up: Effect Sizes for Differences in Estimated Marginal Means of the Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| Contrast | Cohen's *d* | | | | | |
|---|---|---|---|---|---|---|
| | IDS | GADQ IV | SPIN | RRS | PSWQ | PTQ |
| Waitlist control – full RNT-focused intervention [baseline] | -0.06 | 0.02 | 0.05 | -0.04 | 0.03 | 0.05 |
| Waitlist control – concreteness training intervention [baseline] | -0.13 | -0.10 | 0.03 | -0.13 | 0.03 | -0.01 |
| Full RNT-focused – intervention concreteness training intervention [baseline] | -0.07 | -0.12 | -0.02 | -0.09 | -0.01 | -0.06 |
| Waitlist control – full RNT-focused intervention [post-intervention] | 0.07 | -0.04 | 0.14 | 0.09 | 0.09 | 0.01 |
| Waitlist control – concreteness training intervention [post-intervention] | -0.11 | -0.15 | -0.07 | -0.02 | -0.02 | -0.12 |
| Full RNT-focused – intervention concreteness training intervention [post-intervention] | -0.19 | -0.11 | -0.22 | -0.11 | -0.11 | -0.13 |
| Waitlist control – full RNT-focused intervention [follow-up] | -0.02 | 0.07 | 0.05 | -0.005 | 0.13 | 0.05 |
| Waitlist control – concreteness training intervention [follow-up] | -0.23 | -0.01 | -0.04 | -0.08 | 0.01 | -0.01 |
| Full RNT-focused intervention – concreteness training intervention [follow-up] | -0.21 | -0.08 | -0.09 | -0.07 | -0.12 | -0.07 |
| Baseline – post-intervention [wait list control] | 0.08 | 0.26 | -0.01 | 0.08 | 0.12 | 0.28 |
| Baseline – post-intervention [full RNT-focused intervention] | 0.21 | 0.20 | 0.08 | 0.22 | 0.18 | 0.23 |
| Baseline – post-intervention [concreteness training intervention] | 0.09 | 0.21 | -0.12 | 0.19 | 0.08 | 0.16 |
| Baseline – follow-up [wait list control] | 0.06 | 0.19 | -0.03 | 0.17 | 0.12 | 0.26 |
| Baseline – follow-up [full RNT-focused intervention] | 0.10 | 0.24 | -0.04 | 0.20 | 0.22 | 0.26 |
| Baseline – follow-up [concreteness training intervention] | -0.14 | 0.28 | -0.11 | 0.21 | 0.11 | 0.26 |

*Note*. Outcomes in the linear mixed-effects models are total scale scores on the respective measure. The models were estimated based on the intention-to-treat sample.

Appendix E

## Table S4

*Logistic Regressions Predicting Probabilities for Diagnoses of Depression, Generalized Anxiety Disorder, and Social Anxiety Disorder at Follow-Up*

| | **PHQ-9 Diagnosis** | | **GAD-7 Diagnosis** | | **SIAS Diagnosis** | |
|---|---|---|---|---|---|---|
| *Predictors* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* |
| Condition [full RNT-focused intervention] | 1.01<br>0.43 – 2.35 | .979 | 1.39<br>0.41 – 4.68 | 0.589 | 1.04<br>0.47 – 2.23 | .929 |
| Condition [concreteness training intervention] | 1.64<br>0.70 – 3.80 | .250 | 1.74<br>0.51 – 5.93 | 0.363 | 1.03<br>0.44 – 2.31 | .952 |
| Observations | 174 | | 174 | | 174 | |
| $R^2$ Tjur | .009 | | .005 | | .000 | |

*Note*. PHQ-9 diagnosis = total scale score on the Patient Health Questionnaire-9 > 9, GAD-7 diagnosis = total scale score on the Generalized Anxiety Disorder-7 Questionnaire > 9, SIAS diagnosis = total scale score on the Social Interaction Anxiety Scale > 35, $R^2$ Tjur = coefficient of determination by Tjur. The models were estimated based on the completer sample.

## C. Minimum Dose Sensitivity Analyses

### *Dropout among Participants Fulfilling the Minimum Dose Criterion*

Of the minimum dose sample, 85.09% (97 participants, 50 in the full RNT-focused intervention and 48 in the concreteness training intervention) completed the post-intervention assessment. The follow-up assessment was completed by 64.91% of the minimum dose sample (74 participants, 40 in the full RNT-focused intervention and 34 in the concreteness training intervention).

### *Baseline Differences Between Conditions in the Minimum Dose Sample*

Excluding participants according to the minimum dose criterion lead to significant baseline differences in the primary and two secondary outcomes (generalized anxiety symptoms and content-independent RNT) between the concreteness training and one or both other conditions.

**Table S5**

*Minimum Dose Sensitivity Analyses: Means (with SDs) for Scores Primary and Secondary Outcome Measure(s) by Time and Condition*

| | Baseline | | | Post-Intervention | | | Follow-Up | | |
|---|---|---|---|---|---|---|---|---|---|
| | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention | Waitlist Control | Full RNT-Focused Intervention | Concreteness Training Intervention |
| IDS | 15.16 (6.26) | 15.02 (6.50) | 18.02 (6.83) | 13.81 (8.16) | 12.42 (6.20) | 16.49 (9.24) | 14.74 (9.60) | 10.68 (6.22) | 17.35 (11.47) |
| GADQ-IV | 6.64 (2.26) | 6.77 (2.51) | 7.63 (2.02) | 5.63 (2.63) | 5.52 (2.50) | 6.85 (2.82) | 6.25 (2.76) | 5.29 (2.39) | 6.29 (2.75) |
| SPIN | 18.93 (8.87) | 19.58 (10.11) | 19.36 (8.60) | 18.91 (10.88) | 18.54 (10.93) | 21.30 (10.61) | 20.32 (10.66) | 18.60 (12.77) | 20.26 (11.01) |
| RRS | 49.16 (7.63) | 49.17 (6.82) | 51.87 (6.74) | 47.97 (10.17) | 46.42 (10.10) | 48.87 (9.68) | 47.42 (9.99) | 43.95 (9.29) | 48.29 (11.11) |
| PSWQ | 54.33 (8.45) | 53.41 (8.94) | 55.58 (8.25) | 52.56 (9.73) | 50.68 (8.16) | 54.94 (10.03) | 53.49 (9.89) | 48.30 (9.93) | 53.88 (10.04) |
| PTQ | 33.02 (8.79) | 31.44 (9.29) | 35.45 (7.28) | 28.80 (10.17) | 28.10 (8.93) | 32.81 (11.69) | 29.84 (11.00) | 25.95 (9.51) | 30.00 (10.59) |

*Note.* Descrptive statistics were calculated for minimum dose sample using complete cases at each time point. Descriptive statistics for the waitlist control group are included as a point of reference. IDS = Inventory of Depressive Symptomatology, GADQ-IV = Generalized Anxiety Disorder Questionnaire-IV, SPIN = Social Phobia Inventory, RRS = Ruminative Response Scale, PSWQ = Penn State Worry Questionnaire, PTQ = Perseverative Thinking Questionnaire.

**Table S6**

*Minimum Dose Sensitivity Analyses: Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ IV), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| **Outcome** | **IDS** | | **GADQ IV** | | **SPIN** | | **RRS** | | **PSWQ** | | **PTQ** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* |
| Condition [full RNT-focused intervention] | -0.09<br>-2.32 – 2.13 | .936 | 0.13<br>-0.62 – 0.89 | .732 | 0.65<br>-2.41 – 3.71 | .677 | 0.01<br>-2.65 – 2.66 | .997 | -0.92<br>-3.68 – 1.84 | .513 | -1.58<br>-4.47 – 1.32 | .286 |
| Condition [concreteness training intervention] | **2.91**<br>**0.63 – 5.19** | **.012** | **0.99**<br>**0.21 – 1.76** | **.012** | 0.44<br>-2.69 – 3.57 | .784 | 2.71<br>-0.01 – 5.43 | .051 | 1.25<br>-1.57 – 4.08 | .385 | 2.44<br>-0.53 – 5.40 | .107 |
| Time [post-intervention] | -1.13<br>-2.44 – 0.19 | .092 | **-0.95**<br>**-1.37 – -0.53** | **<.001** | 0.14<br>-1.29 – 1.58 | .845 | -1.14<br>-2.76 – 0.49 | .170 | **-1.62**<br>**-3.07 – -0.16** | **.029** | **-3.88**<br>**-5.65 – -2.10** | **<.001** |
| Condition [full RNT-focused intervention] * time [post-intervention] | -1.53<br>-3.80 – 0.74 | .187 | -0.20<br>-0.93 – 0.53 | .596 | -1.71<br>-4.21 – 0.79 | .180 | -1.82<br>-4.65 – 1.01 | .207 | -1.45<br>-3.98 – 1.08 | .262 | 0.12<br>-2.97 – 3.20 | .941 |
| Condition [concreteness training intervention] * time [post-intervention] | -0.56<br>-2.88 – 1.77 | .639 | 0.11<br>-0.64 – 0.85 | .781 | 1.32<br>-1.23 – 3.88 | .310 | -1.75<br>-4.63 – 1.14 | .236 | 0.77<br>-1.81 – 3.36 | .558 | 1.24<br>-1.92 – 4.39 | .442 |
| **Random Effects** | | | | | | | | | | | | |
| $\sigma^2$/ $\tau 00$ | 23.20/ 27.79 | | 2.40/ 3.49 | | 27.86/ 68.86 | | 36.22/ 36.88 | | 28.75/ 50.21 | | 43.20/43.53 | |
| *ICC*/ *N* (participants) | 0.55/ 236 | | 0.59/ 236 | | 0.71/ 236 | | 0.50/ 236 | | 0.64/ 236 | | 0.50/ 236 | |
| Observations | 432 | | 434 | | 434 | | 434 | | 434 | | 434 | |
| Marginal/ Conditional $R^2$ | .045 / .566 | | .067 / .621 | | .005 / .713 | | .029 / .519 | | .027 / .646 | | .063 / .533 | |

*Note*. Outcomes are total scale scores on the respective measure. The models were estimated based on the minimum dose sample. Reference level for condition is

the waitlist control condition and reference level for time is baseline. $\sigma^2$= within-participant variability, $\tau_{00}$ = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional $R^2$ = Proportion of variance explained by fixed/ by fixed and random effects. Participants in the intervention condition are participants fulfilling the pre-defined minimum-dose criterion. Significant baseline between conditions in many of the outcomes might have contributed to significant main effects of condition in some of the models.

**Table S7**

*Minimum Dose Sensitivity Analyses: Effect Sizes for Differences in Estimated Marginal Means of the Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| Contrast | Cohen's *d* | | | | | |
|---|---|---|---|---|---|---|
| | IDS | GADQ IV | SPIN | RRS | PSWQ | PTQ |
| Waitlist control – full RNT-focused intervention [baseline] | 0.01 | -0.04 | -0.05 | 0.00 | 0.07 | 0.12 |
| Waitlist control – concreteness training intervention [baseline] | -0.29 | -0.29 | -0.03 | -0.22 | -0.10 | -0.19 |
| Full RNT-focused – intervention concreteness training intervention [baseline] | -0.30 | -0.25 | 0.02 | -0.22 | -0.17 | -0.30 |
| Waitlist control – full RNT-focused intervention [post-intervention] | 0.16 | 0.02 | 0.08 | 0.15 | 0.19 | 0.11 |
| Waitlist control – concreteness training intervention [post-intervention] | -0.23 | -0.32 | -0.12 | -0.08 | -0.16 | -0.28 |
| Full RNT-focused – intervention concreteness training intervention [post-intervention] | -0.39 | -0.34 | -0.21 | -0.23 | -0.35 | -0.39 |
| Baseline – post-intervention [wait list control] | 0.11 | 0.27 | -0.01 | 0.09 | 0.13 | 0.29 |
| Baseline – post-intervention [full RNT-focused intervention] | 0.26 | 0.34 | 0.12 | 0.24 | 0.24 | 0.29 |
| Baseline – post-intervention [concreteness training intervention] | 0.16 | 0.25 | -0.11 | 0.24 | 0.07 | 0.20 |

*Note*. Outcomes in the linear mixed-effects models are total scale scores on the respective measure. The models were estimated based on the minimum dose sample.

## Table S8

*Minimum Dose Sensitivity Analyses: Logistic Regressions Predicting Probabilities of Meeting Criteria for Diagnoses of Depression, Generalized Anxiety Disorder, and Social Anxiety Disorder at Post-Intervention*

| | **PHQ-9 Diagnosis** | | **GAD-7 Diagnosis** | | **SIAS Diagnosis** | |
|---|---|---|---|---|---|---|
| *Predictors* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* |
| Condition [full RNT-focused intervention] | 1.01<br>0.26 – 3.39 | .986 | 0.65<br>0.14 – 2.31 | .536 | 1.08<br>0.45 – 2.49 | .862 |
| Condition [concreteness training intervention] | 1.70<br>0.53 – 5.20 | .353 | 1.50<br>0.47 – 4.43 | .472 | 1.48<br>0.64 – 3.35 | .351 |
| Observations | 198 | | 198 | | 198 | |
| $R^2$ Tjur | .005 | | .007 | | .005 | |

*Note*. PHQ-9 diagnosis = total scale score on the Patient Health Questionnaire-9 > 9, GAD-7 diagnosis = total scale score on the Generalized Anxiety Disorder-7 Questionnaire > 9, SIAS diagnosis = total scale score on the Social Interaction Anxiety Scale > 35, $R^2$ Tjur = coefficient of determination by Tjur. The models were estimated based on the minimum dose completer sample.

**Table S9**

*Minimum Dose Sensitivity Analyses - Effects at Follow-Up: Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ IV), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| | **IDS** | | **GADQ IV** | | **SPIN** | | **RRS** | | **PSWQ** | | **PTQ** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Predictors* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* | *B (CI)* | *p* |
| Condition [full RNT-focused intervention] | -0.09<br>-2.48 – 2.30 | .942 | 0.13<br>-0.64 – 0.90 | .737 | 0.65<br>-2.49 – 3.79 | .685 | 0.01<br>-2.77 – 2.78 | .997 | -0.92<br>-3.75 – 1.91 | .523 | -1.58<br>-4.55 – 1.40 | .300 |
| Condition [concreteness training intervention] | **2.91**<br>**0.47 – 5.36** | **.020** | **0.99**<br>**0.20 – 1.77** | **.014** | 0.44<br>-2.78 – 3.66 | .790 | 2.71<br>-0.13 – 5.55 | .061 | 1.25<br>-1.64 – 4.15 | .396 | 2.44<br>-0.61 – 5.49 | .117 |
| Time [post-intervention] | -0.97<br>-2.36 – 0.41 | .169 | **-0.92**<br>**-1.33 – -0.51** | **<.001** | 0.19<br>-1.29 – 1.67 | .806 | -1.03<br>-2.71 – 0.65 | .228 | **-1.50**<br>**-2.96 – -0.04** | **.044** | **-3.84**<br>**-5.61 – -2.07** | **<.001** |
| Time [follow-up] | -0.73<br>-2.29 – 0.83 | .360 | **-0.67**<br>**-1.13 – -0.20** | **.005** | 0.41<br>-1.25 – 2.08 | .628 | **-2.13**<br>**-4.01 – -0.25** | **.027** | -1.53<br>-3.17 – 0.11 | .068 | **-3.54**<br>**-5.52 – -1.56** | **<.001** |
| Condition [full RNT-focused intervention] * time [post-intervention] | -1.74<br>-4.14 – 0.66 | .156 | -0.23<br>-0.95 – 0.49 | .537 | -1.81<br>-4.38 – 0.77 | .168 | -1.95<br>-4.87 – 0.96 | .189 | -1.64<br>-4.18 – 0.90 | .206 | 0.01<br>-3.06 – 3.09 | .993 |
| Condition [concreteness training intervention] * time [post-intervention] | -0.71<br>-3.17 – 1.74 | .569 | 0.07<br>-0.66 – 0.81 | .846 | 1.28<br>-1.35 – 3.92 | .340 | -1.85<br>-4.83 – 1.14 | .225 | 0.65<br>-1.95 – 3.25 | .623 | 1.20<br>-1.95 – 4.34 | .456 |
| Condition [full RNT-focused intervention] * time [follow-up] | **-4.05**<br>**-6.69 – -1.42** | **.003** | **-0.80**<br>**-1.59 – -0.00** | **.049** | -2.57<br>-5.40 – 0.26 | .075 | -3.04<br>-6.24 – 0.16 | .062 | **-3.08**<br>**-5.87 – -0.28** | **.031** | -1.54<br>-4.91 – 1.83 | .371 |
| Condition [concreteness training intervention] * time [follow-up] | -0.06<br>-2.83 – 2.70 | .964 | -0.68<br>-1.51 – 0.16 | .111 | 0.06<br>-2.92 – 3.03 | .970 | -1.21<br>-4.56 – 2.14 | .480 | -0.11<br>-3.04 – 2.82 | .940 | -1.33<br>-4.87 – 2.21 | .461 |

| **Random Effects** | | | | | | |
|---|---|---|---|---|---|---|
| $\sigma^2$/ $\tau_{00}$ | 25.95/ 32.92 | 2.35/ 3.76 | 29.65/ 72.72 | 38.65/ 40.89 | 29.04/ 53.71 | 42.93/ 48.84 |
| *ICC*/ *N* (participants) | 0.56/ 236 | 0.62/ 236 | 0.71/ 236 | 0.51/ 236 | 0.65/ 236 | 0.53/ 236 |
| Observations | 579 | 582 | 582 | 582 | 582 | 582 |
| Marginal / Conditional $R^2$ | .058 / .585 | .063 / .640 | .006 / .712 | .040 / .534 | .037 / .662 | .065 / .563 |

*Note*. Outcomes are total scale scores on the respective measure. The models were estimated based on the minimum dose sample. Reference level for condition is the waitlist control condition and reference level for time is baseline. $\sigma^2$= within-participant variability, $\tau_{00}$ = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional $R^2$ = Proportion of variance explained by fixed/ by fixed and random effects. Participants in the intervention condition are participants fulfilling the pre-defined minimum-dose criterion. Significant baseline between conditions in many of the outcomes might have contributed to significant main effects of condition in some of the models.

**Table S10**

*Minimum Dose Sensitivity Analyses - Effects at Follow-Up: Effect Sizes for Differences in Estimated Marginal Means of the Linear Mixed-Effects Models Predicting Depressive Symptoms (IDS), Generalized Anxiety Symptoms (GADQ), Social Anxiety Symptoms (SPIN), Rumination (RRS), Worrying (PSWQ), and Content-Independent Repetitive Negative Thinking (PTQ)*

| Contrast | Cohen's *d* | | | | | |
|---|---|---|---|---|---|---|
| | IDS | GADQ IV | SPIN | RRS | PSWQ | PTQ |
| Waitlist control – full RNT-focused intervention [baseline] | 0.01 | -0.04 | -0.05 | 0.00 | 0.07 | 0.12 |
| Waitlist control – concreteness training intervention [baseline] | -0.27 | -0.28 | -0.03 | -0.21 | -0.10 | -0.18 |
| Full RNT-focused – intervention concreteness training intervention [baseline] | -0.28 | -0.25 | 0.02 | -0.21 | -0.17 | -0.30 |
| Waitlist control – full RNT-focused intervention [post-intervention] | 0.17 | 0.03 | 0.08 | 0.15 | 0.20 | 0.12 |
| Waitlist control – concreteness training intervention [post-intervention] | -0.20 | -0.30 | -0.12 | -0.07 | -0.15 | -0.27 |
| Full RNT-focused – intervention concreteness training intervention [post-intervention] | -0.37 | -0.33 | -0.20 | -0.22 | -0.35 | -0.38 |
| Waitlist control – full RNT-focused intervention [follow-up] | 0.38 | 0.19 | 0.13 | 0.24 | 0.31 | 0.23 |
| Waitlist control – concreteness training intervention [follow-up] | -0.26 | -0.09 | -0.04 | -0.12 | -0.09 | -0.08 |
| Full RNT-focused intervention – concreteness training intervention [follow-up] | -0.65 | -0.28 | -0.17 | -0.36 | -0.40 | -0.31 |
| Baseline – post-intervention [wait list control] | 0.09 | 0.27 | -0.01 | 0.08 | 0.12 | 0.28 |
| Baseline – post-intervention [full RNT-focused intervention] | 0.25 | 0.33 | 0.12 | 0.24 | 0.25 | 0.28 |
| Baseline – post-intervention [concreteness training intervention] | 0.16 | 0.24 | -0.11 | 0.23 | 0.07 | 0.20 |
| Baseline – follow-up [wait list control] | 0.07 | 0.19 | -0.03 | 0.16 | 0.12 | 0.26 |
| Baseline – follow-up [full RNT-focused intervention] | 0.44 | 0.42 | 0.15 | 0.41 | 0.36 | 0.38 |
| Baseline – follow-up [concreteness training intervention] | 0.07 | 0.39 | -0.03 | 0.26 | 0.13 | 0.36 |

*Note*. Outcomes in the linear mixed-effects models are total scale scores on the respective measure. The models were estimated based on the minimum dose sample.

**Table S11**

*Minimum Dose Sensitivity Analyses - Effects at Follow-Up: Simple Slope Tests Following up Significant Interactions. Slopes for Baseline to Follow-Up Change are Displayed*

| Outcome | Simple Slope | *B* | *t* | *p* |
|---|---|---|---|---|
| IDS | | | | |
| | Baseline – follow-up [waitlist control] | -0.73 | -0.92 | 0.36 |
| | Baseline – follow-up [full RNT-focused intervention] | **-4.80** | **-4.41** | **<.001** |
| GADQ | | | | |
| | Baseline – follow-up [waitlist control] | -0.67 | -2.80 | <.01 |
| | Baseline – follow-up [full RNT-focused intervention] | **-1.46** | **-4.47** | **<.001** |
| PSWQ | | | | |
| | Baseline – follow-up [waitlist control] | -1.53 | -1.83 | .07 |
| | Baseline – follow-up [full RNT-focused intervention] | **-4.61** | **-4.00** | **<.001** |

*Note*. Outcomes in the linear mixed-effects models are total scale scores on the respective measure. The models were estimated based on the minimum dose sample.

**Table S12**

*Minimum Dose Sensitivity Analyses: Logistic Regressions Predicting Probabilities of Meeting Criteria for Diagnoses of Depression, Generalized Anxiety Disorder and Social Anxiety Disorder at Follow-Up*

| | **PHQ-9 diagnosis** | | **GAD-7 diagnosis** | | **SIAS diagnosis** | |
|---|---|---|---|---|---|---|
| *Predictors* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* | *Odds Ratios (CI)* | *p* |
| Condition [full RNT-focused intervention] | 0.40<br>0.11 – 1.20 | 0.128 | 0.60<br>0.08 – 2.74 | 0.539 | 0.73<br>0.29 – 1.76 | 0.497 |
| Condition [concreteness training intervention] | 1.51<br>0.59 – 3.77 | 0.381 | 1.51<br>0.36 – 5.68 | 0.545 | 0.54<br>0.18 – 1.43 | 0.236 |
| Observations | 148 | | 148 | | 148 | |
| $R^2$ Tjur | .030 | | .008 | | .011 | |

*Note*. PHQ-9 diagnosis = total scale score on the Patient Health Questionnaire-9 > 9, GAD-7 diagnosis = total scale score on the Generalized Anxiety Disorder-7 Questionnaire > 9, SIAS diagnosis = total scale score on the Social Interaction Anxiety Scale > 35, $R^2$ Tjur = coefficient of determination by Tjur. The models were estimated based on the minimum dose completer sample.