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Can an app designed to reduce repetitive negative thinking decrease depression and anxiety in young people? Results from a randomized controlled prevention trial

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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-year-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, exploratory analyses using a 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 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: RNT-focused prevention via a self-help app did not decrease depression and anxiety, presumably due to too little engagement with the app content provided.

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., 2020, 2022; 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

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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., 2024). 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, 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 pre-registered 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. In addition, we ran several exploratory analyses. As decreases in sub-threshold symptoms are precursors but no direct test of preventive effects, we 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 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 0.05). 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).

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 - *Mood tracker*	Identifying triggers of RNT and stress	- *Challenge:* Personal warning signs
Concreteness training	- *Challenge*: Abstract versus concrete thinking - *Tool:* Concrete thinking	Concreteness training	- *Challenge*: Abstract versus concrete thinking - *Tool*: Concrete thinking
Engaging in opposite Action	- *Tool:* Opposite Action		
Self-compassion	- *Challenge:* Kind versus unkind self-talk - *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.

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: $0.74 \leq \alpha \leq .88$).

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: $0.84 \leq \alpha \leq .91$).

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: $0.89 \leq \alpha \leq .93$).

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: $0.79 \leq \alpha \leq .91$).

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: $0.85 \leq \alpha \leq .92$).

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: $0.35 \leq \alpha \leq .81$; note that the low internal consistency at baseline [0.35] 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: $0.44 \leq \alpha \leq .76$; 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., 2010) was used to make tentative diagnoses of SAD (in the current study: $0.79 \leq \alpha \leq .90$).

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., 2024). 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. Tools and Challenges took approximately 15 min to complete. 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-

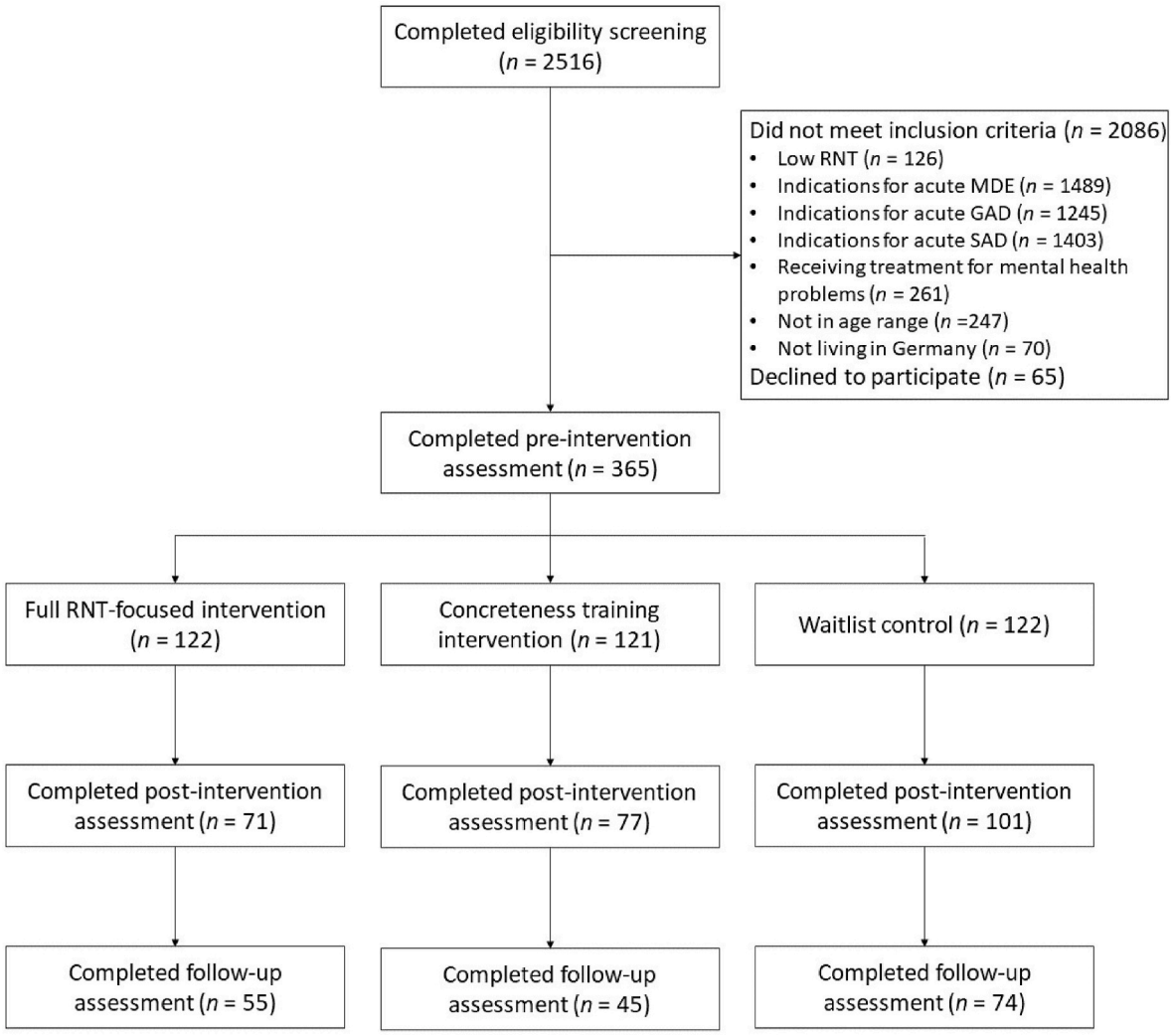

Fig. 1. CONSORT Trial Flow Chart
Note. RNT = repetitive negative thinking, MDE = Major Depressive Episode, GAD = Generalized Anxiety Disorder, SAD = Social Anxiety Disorder.

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 Fig. 1. Following 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

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.

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.

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

Analyses of Pre-Registred Hypotheses. 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. 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.

Exploratory Analyses. 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. Logistic regressions were complete cases analyses using only data from participants who completed the post-intervention assessment.

2.6.2. Exploratory analyses of effects at follow-up

Analyses of effects at post-intervention were adapted to investigate whether the predicted effects extended to the follow-up timepoint. The reference level for effects at follow-up was baseline.

2.6.3. Exploratory comparison of the active conditions

Following the confirmation of the predictions that the full RNT-focused intervention and the concreteness training intervention would reduce symptoms relative to waitlist, we planned to conduct Bayesian analyses to test whether the two interventions had equal effects on the outcomes.

2.6.4. Exploratory 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 minimum dose criterion to participants in the waitlist control condition. The minimum dose criterion was defined in the statistical analyses plan before data analysis (see statistical analysis plan, https://drks.de/search/de/trial/DRKS00027384). It is 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

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. Descriptive 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 −1.20 – 2.69	0.452	−0.07 −0.68 – 0.54	0.831	−0.71 −3.13 – 1.71	0.563	0.53 −1.63 – 2.69	0.629	−0.42 −2.61 – 1.78	0.709	−0.75 −3.11 – 1.62	0.536
Condition [concreteness training intervention]	1.57 −0.38 – 3.52	0.115	0.35 −0.26 – 0.96	0.262	−0.46 −2.89 – 1.96	0.708	1.63 −0.54 – 3.79	0.140	−0.32 −2.52 – 1.88	0.776	0.13 −2.24 – 2.50	0.913
Time [post-intervention]	−1.11 −2.46 – 0.25	0.109	**−.95** **−1.36–-.54**	**<.001**	0.13 −1.37 – 1.64	0.861	−1.13 −2.74 – 0.47	0.167	**−1.61** **−3.01–-.22**	**.023**	**−3.85** **−5.57–-2.13**	**<.001**
Condition [full RNT-focused intervention]*time [post]	−1.63 −3.69 – 0.44	0.122	0.19 −0.43 – 0.82	0.541	−1.72 −4.03 – 0.59	0.145	−1.97 −4.42 – 0.49	0.117	−0.78 −2.92 – 1.37	0.478	0.62 −2.01 – 3.25	0.645
Condition [concreteness training intervention] *time [post]	−0.12 −2.15 – 1.91	0.909	0.21 −0.40 – 0.82	0.500	1.46 −0.80 – 3.72	0.207	−1.24 −3.65 – 1.17	0.312	0.60 −1.50 – 2.70	0.578	1.61 −0.98 – 4.19	0.223
Random Effects												
σ^2/τ_{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	0.021/0.596		0.034/0.630		0.009/0.675		0.021/0.532		0.010/0.659		0.030/0.557	

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).

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, σ^2 = within-participant variability, τ_{00} = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional R^2= Proportion of variance explained by fixed/by fixed and random effects.

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.

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 Figs. 1 and 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, $t(232.7) = 0.14$, $p = .88$, $d = -0.02$. 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

3.4.1. Analyses of Pre-registered hypotheses

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).

3.4.2. Exploratory analyses

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. Exploratory analyses of 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, Tables 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. Exploratory comparison of the active conditions

Neither the full RNT-focused intervention nor the concreteness training intervention showed superiority relative to the waitlist in the intention-to-treat analyses. Thus, the test of equality between the interventions became superfluous and was therefore omitted from the analyses.

3.7. Exploratory 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, S7, 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 Tables 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 $d = 0.36$ to 0.44) compared with the other two conditions (Cohen's d mostly <0.20), see Supplementary Material, Table S10. Differences between ITT and minimum dose analyses are illustrated in Fig. 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). Note that excluding participants based

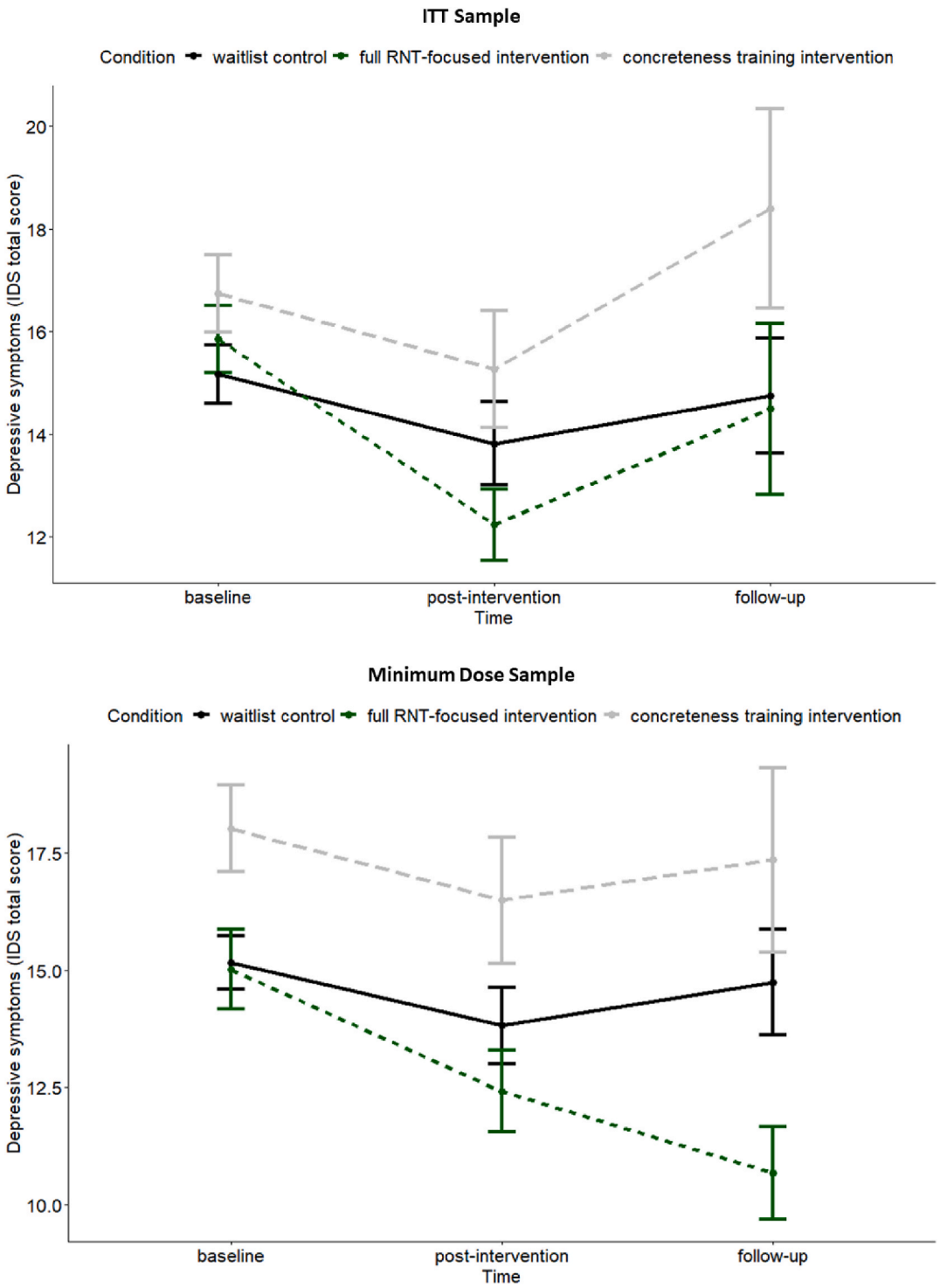

Fig. 2. Mean depressive symptoms with standard error bars over the course of the trial by Condition
Note. ITT = intention-to-treat.

on the minimum dose criterion led to signficiant baseline differences in depressive symptoms, generalized anxiety symptoms, and content-independent RNT between the concreteness training condition and one or both other conditions (see Supplementary Material).

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, exploratory sensitivity analyses gave tentative indications that the more extensive full RNT-focused intervention app could have beneficial effects when used with adequate frequency. Specifically, participants in the full RNT-focused intervention condition who fulfilled a minimum dose criterion reported greater decreases in

depressive symptoms 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., 2024; 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). For example, in the in the study by Topper et al., 2019, participants on average completed four 90-min web-based intervention sessions, which equals 360 min engagement with the intervention contents. In contrast, in the current trial, participants in the intervention conditions on average completed three 15-min tools or challenges, which equals 45 min engagement with the intervention. 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 exploratory minimum dose analyses suggested that participants who used the full RNT-focused intervention app more showed significant improvements at follow-up. It is important to note that effects took until the follow-up time point to unfold and that the results are based on exploratory analyses, and thus should be replicated in future studies. Nevertheless, our findings contribute evidence that in order to design effective, scalable RNT-focused app interventions, finding ways to increase usage rates could be a key factor.

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. 2024 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 slightly more positive results in the full RNT-focused intervention condition in the exploratory minimum dose sensitivity analyses might be a results of even lower usage rates and less participants fulfilling the minimum dose criterium in the concreteness training condition. In addition, excluding participants according to the minimum dose criterion led to significant baseline differences in some outcomes between the concreteness training and one or both other conditions, which might have influenced the results. 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 is a promising strategy for the prevention of psychopathology in at-risk adolescents and young adults. While self-help apps could increase the scalability of RNT-focused interventions, the current trial indicates that the unguided format compromises efficacy. It is likely that the null findings are due to too little engagement with the intervention content provided, considering the overall low usage rates. For scalable RNT-focused interventions to be effective, it therefore seems important to deliver them in highly engaging formats.

CRediT authorship contribution statement

Julia Funk: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Johannes Kopf-Beck:** Writing – review & editing, Methodology. **Keisuke Takano:** Writing – review & editing, Formal analysis. **Edward Watkins:** Writing – review & editing, Conceptualization. **Thomas Ehring:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbtep.2024.102014.

Data availability

Data set, code book, and analytic code are available at https://drks.de/search/de/trial/DRKS00027384

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