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Efficacy of a smartphone-based Cognitive Bias Modification program for emotion regulation: A randomized-controlled crossover trial

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ABSTRACT

Previous research has identified maladaptive emotion regulation as a key factor in psychopathology. Thus, addressing emotion regulation via scalable, low-threshold digital interventions – such as smartphone-based Cognitive Bias Modification (CBM) – holds important therapeutic potential. Using a randomized-controlled crossover trial, we tested the efficacy of an integrated CBM module within the Affect Regulation Training (ART, i.e., CBM-ART) that targeted emotion regulation through elements of appraisal-based and approach avoidance training.

Undergraduate students reporting elevated stress were randomized to a one-week active intervention (*Mindgames*; including psychoeducation, a quiz, and CBM-ART; $n = 40$), active control training (*Emo Shape*; including placebo psychoeducation, a quiz, and a placebo swiping task; $n = 36$) or waitlist ($n = 25$). Before and after the intervention, we assessed emotion regulation, interpretation bias, stress and depression. We further tested post-training stress reactivity using an anagram task.

Results indicated that the active intervention improved negative (OR = 0.35) and positive (OR = 2.40) interpretation biases and symptom measures ($d = 0.52$–0.87). However, active control training showed attenuated concurrent pre-post changes on interpretation biases (i.e., OR = 0.53 for negative, and OR = 1.49 for positive interpretations) and symptom measures ($d = 0.26$–0.91). The active intervention was rated positively in terms of acceptability and usability.

These findings provide initial evidence for the efficacy and acceptability of an integrated app-based CBM intervention for emotion regulation in reducing interpretation biases and psychopathological symptoms, including stress. However, future studies should disentangle specific mechanisms underlying interventional effects.

1. Introduction

Regulating one's own emotions – i.e., influencing their flow as per subjective needs, goals and situational demands (Gross, 2014) – is integral to the human experience. Consistently, the myriad of models describing emotion regulation (e.g., see Sheppes et al., 2015) converge on the notion that it is ubiquitous in daily life, entailing a cyclic process that involves strategies like situation selection or modification, attentional deployment, cognitive reappraisal, and response modulation (Gross, 2014). Deficits in recruiting these strategies have been linked to psychopathology, e.g., including depression and anxiety disorders (Aldao et al., 2016; Sloan et al., 2017). Notably, emotion regulation deficits have been found to be particularly relevant for elevated stress, a strong predictor in the onset and maintenance of mental disorders (e.g., Wang and Saudino, 2011). As chronic stress is prevalent in the general population (Hapke et al., 2013), targeting it during intervention programs appears paramount to address its harmful long-term consequences, such as increased morbidity, health burden and reduced quality of life (Larzelere and Jones, 2008). Thus, leveraging emotion regulation as a pathway to alleviating stress constitutes an intriguing possibility to improve emotional well-being within both the general population and individuals at risk of developing a mental disorder.

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Consistent with this endeavor, previous studies have investigated the effects of interventions that remediate emotion regulation deficits. Specifically, one study showed that cognitive-behavioral therapy (CBT) augmented with an emotion regulation training, vs. routine CBT, led to decreases in negative affect as well as increases in well-being and emotion regulation skills in individuals with depression (Berking et al., 2013). Relatedly, a second study found decreases in anxiety and stress following CBT enhanced with an emotion regulation training (Sobhi-Gharamaleki et al., 2015). Overall, these studies illustrate the potential of emotion regulation trainings in the treatment of psychopathology. However, as they employed integrative CBT programs featuring disorder-specific emotion regulation trainings, they do not provide evidence about the more fine-grained efficacy of standalone, transdiagnostic protocols.

Addressing these limitations, Berking (2008) developed the Affect Regulation Training (ART) as a transdiagnostic approach to enhancing emotion regulation (Berking and Whitley, 2014; Berking and Lukas, 2015). ART is based on the Adaptive Coping with Emotions Model which defines nine adaptive emotion regulation skills: (1) becoming aware of one's emotions, (2) identifying and labeling them, (3) accurately interpreting emotion-related bodily sensations, (4) understanding prompts inherent to emotions, (5) modifying negative emotions, (6) accepting negative emotions where necessary, (7) tolerating currently unchangeable emotions, (8) confronting avoided situations to attain one's goals, and (9) supporting oneself compassionately (Berking, 2008). Together, these coping strategies are mapped onto seven empirically grounded skills that are targeted in each ART module, i.e.: muscle relaxation, breathing relaxation, nonjudgmental emotional awareness, acceptance and tolerance, compassionate self-support, analyzing emotions, and modifying emotions. Extant research on the ART program evidences its benefits, including improvements in depression (e.g., Berking et al., 2019) and binge eating disorder (Berking et al., 2022) within waitlist-controlled trials. Notably, ART has recently been adapted as a smartphone application complementing face-to-face treatment (ART-app; Böhme and Berking, 2021). This application features psychoeducational audio sequences, exercises, and an ART coach providing help and feedback on participant progress, thereby mirroring ART's face-to-face structure. Overall, the ART-app represents an important step in augmenting effects of the face-to-face program, further providing grounds for the development of a standalone version. However, to develop and improve the ART-app, it appears vital to investigate the efficacy of its core components to tailor and evaluate intervention content.

A central component of the ART-app is the *Mindgames* module, an intervention that involves Cognitive Bias Modification (CBM). Briefly, CBM aims to alleviate psychopathological symptoms through practice-related automatization of adaptive processing styles, employing associative learning principles and operant conditioning (e.g., MacLeod and Mathews, 2012). Importantly, CBM programs are easily administrable without a rationale, thus rendering them inclusive, low-threshold and scalable intervention tools. Overall, extant research indicates beneficial effects of CBM, including appraisal (e.g., Woud et al., 2021) and approach-avoidance trainings (e.g., Fodor et al., 2017), for various disorders, i.e., most consistently for anxiety disorders (see Fodor et al., 2020, Martinelli et al., 2022, for current meta-analyses). Further, CBM efficacy has increasingly been demonstrated for smartphone-based administration (e.g., Yang et al., 2017, Kakoschke et al., 2018; see Zhang et al., 2018, for a review). Overall, these findings highlight the promise of CBM in the prevention and treatment of mental disorders.

Harnessing this potential, within the *Mindgames* module and the CBM-ART component, participants are requested to evaluate statements – i.e., cognitions – related to the appraisal of emotions and emotion regulation strategies, as mapped onto ART skills (e.g., Berking and Whitley, 2014). If participants judge a statement to be correct (i.e., helpful), they may pull it towards themselves, with the cognition and the concurrent image increasing in size. Conversely, if participants judge a statement to be incorrect (i.e., not helpful), they may push it away from them, with stimuli decreasing in size. To enhance adaptive cognitions about emotions and emotion regulation, participants receive decision-contingent feedback at a 100% rate (i.e., feedback and reward points). Thus, CBM-ART combines aspects of an appraisal bias retraining (i.e., in that it aims to modify appraisals of emotions and emotion regulation strategies) and approach-avoidance retraining (i.e., in that it employs a push-pull dynamic aiming to increase approach of functional, and avoidance of dysfunctional, cognitions). Conceptually, the module is grounded in cognitive-behavioral theories postulating that the post-hoc appraisal of emotions and concurrent emotion regulation strategies may be biased and that these biases are linked to psychopathology (e.g., Mehu and Scherer, 2015). To illustrate, rigidly judging emotions as dangerous - as opposed to accepting and gently modifying them - may foster psychopathological symptoms. Thus, enhancing adaptive post-hoc emotion appraisal through CBM may improve emotion regulation and lower stress. However, to date, the therapeutic potential of such smartphone-based, transdiagnostic emotion regulation CBM remains largely unknown.

Addressing these research gaps, the current study aimed to explore the effects of a novel CBM paradigm to modulate post-hoc emotional appraisal biases and thus enhance emotion regulation. In this trial, individuals reporting elevated stress were randomized to a one-week active intervention (*Mindgames*) including CBM for emotion regulation (CBM-ART), vs. an active condition *(Emo Shape)* comprising a swiping task (Control Condition; CC), vs. a time-equivalent waitlist condition (Waitlist Condition; WLC), with WLC participants being subsequently randomized to one of the active conditions. This design was chosen to differentiate training effects related to CBM-ART components from non-specific factors (e.g., practice effects in the CC). More specifically, CBM-ART and CC were closely matched (e.g., containing identical structure, length, duration, and intensity), thus creating a "placebo-active" (see Goldberg et al., 2023) that would allow for an approximative isolation of "active training ingredients" (see Blackwell et al., 2017).

We predicted that participants receiving CBM-ART, vs. CC and WLC, would show reduced interpretation bias regarding emotion regulation, increased emotion regulation skills, reduced stress, reduced depression, and reduced stress reactivity during an anagram task. Following evidence on attenuated effects for CBM control conditions (e.g., Fodor et al., 2020; Martinelli et al., 2022), we predicted the CC, vs. CBM-ART and WLC, to exhibit attenuated reductions in interpretation bias, symptoms and stress reactivity. Further, we predicted effects to be stable up to follow-ups. We further explored usability and acceptability of CBM-ART.

2. Methods

2.1. Trial design

This study was a randomized-controlled crossover trial with three (i.e., for CBM-ART, CC) or four (i.e., for WLC) assessment points. As shown in Fig. 1, upon completing the online screening, participants were randomly assigned to CBM-ART, CC or WLC.

As part of a crossover design, participants that had completed the WLC were again randomized to CBM-ART or CC following the Pre-II-Assessment. Specifically, a crossover design was chosen to yield a more efficient comparison of condition effects, thus requiring fewer participants than a parallel design.

Participants were randomized following a randomization plan generated through http://randomization.com/. For the WLC, all pre- to post (i.e., Pre-I to Pre-II) changes in bias and symptom scores were non-significant (i.e., all $ps \geq .166$), thus indicating no substantial carry-over effects. Data collection in this study was conducted between 10/2020 and 07/2021. The study protocol was approved by the local ethics commitee at the Faculty of Psychology and Sports Science (University of Muenster).

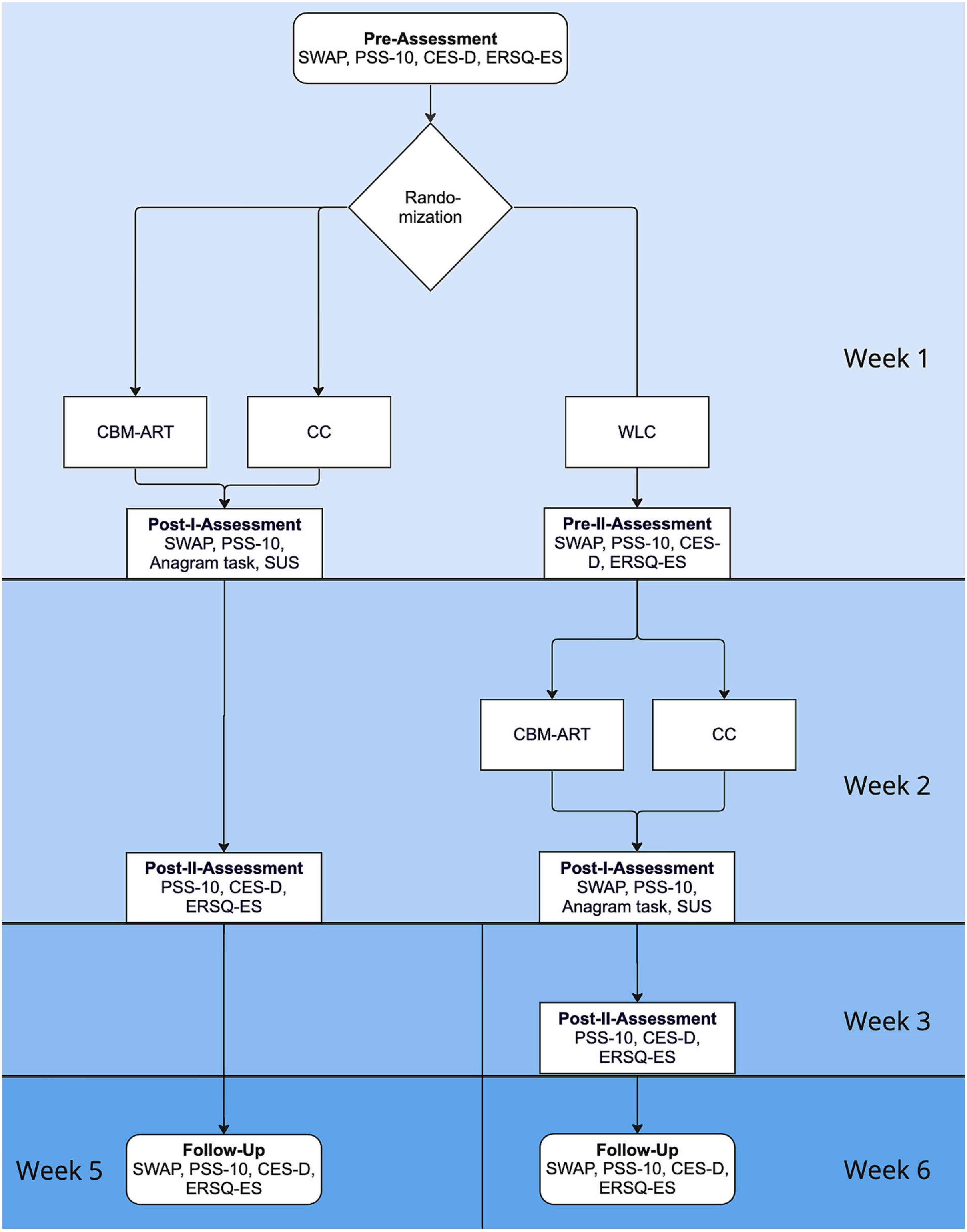

Fig. 1. Study procedure.
Notes. CBM-ART = Cognitive Bias Modification-Affect Regulation Training, CC=Control Condition, CES-D=Center For Epidemiologic Studies Depression Scale, ERSQ-ES = Emotion Regulation Skills Questionnaire-Emotion Specific Instrument, PSS-10 = Perceived Stress Scale-10, SUS=System Usability Scale, SWAP=Sentence Word Association Paradigm, WLC=Waitlist Condition.

2.2. Participants

Participants were recruited via postings, flyers, and student social media groups. Inclusion criteria were: 1) aged between 18 and 65 years; 2) active enrollment in study course; 3) have access to device with an Android-based operating system (e.g., phone or tablet) and desktop/laptop computer; 4) experienced elevated stress (i.e., score of ≥8 on the Perceived Stress Scale; PSS–4, Cohen et al., 1983); 5) have no acute suicidality (i.e., score of <3 on the Depressive Symptom Inventory-Suicidality Subscale; DSISS, von Glischinski et al., 2016).

Fig. 2 summarizes participant flow according to the Consolidated Standards for Reporting Trials (CONSORT) statement for crossover trials (Dwan et al., 2019). Overall, $N = 94$ (CBM-ART: $n = 33$, CC: $n = 29$, WLC: $n = 32$) individuals were randomized, with $n = 17$ (18.09%) individuals dropping out before receiving the allocated intervention and one individual (1.06%) being excluded due to erroneously accessing the intervention before pre-assessment. The remaining $n = 79$ (80.85%) participants completed all assessment points (CBM-ART: $n = 26$, CC: $n = 24$, WLC: $n = 26$), with WLC participants crossing over to the other two conditions. Cases with extreme outliers in the number of completed swiping sessions were excluded ($n = 4$; i.e., $n = 2$ from CC, $n = 1$ from WLC with subsequent CBM-ART). These cases were eliminated due to substantial training irregularities (i.e., with one participant not conducting training sessions, and two participants yielding excessively high numbers of training sessions exceeding the 1.5 * interquartile range relative to the respective mean in swiping sessions). Overall, due to technical difficulties, 2.98% of data could not be recorded and was treated as missing data.

2.3. Measures and materials[1]

2.3.1. Screening

To identify elevated stress, we used the four-item PSS-4. Further, to rule out suicidality, we employed the four-item DSISS.

2.3.2. Primary outcome measures

2.3.2.1. Interpretation bias: Sentence Word Association Paradigm (SWAP). We used an adapted version of the Sentence Word Association Paradigm (SWAP; Dietel et al., 2018, 2020) to assess interpretation bias with regards to emotions and emotion regulation. In this task, during assessment, 160 ambiguous sentence-word-combinations (i.e., including 50% positive, vs. 50% negative words) were presented once, supplemented by 10 practice trials before each assessment. These 160 items were evenly assigned to four verbally accessible ART skills (i.e., 1) “Accepting and Tolerating”, 2) “Effective Self-Support”, 3) “Analyzing” and 4) “Regulating”).

Trials started with a black fixation cross, displayed in the center of a white screen for 500 ms, replaced by an ambiguous sentence. After 3500 ms, the interpretation appeared centrally. Participants had to indicate as fast as possible whether sentence and word were related (i.e., pressing L/“Yes” vs. S/“No” on keyboard). The next trial was initiated upon button press.

2.3.2.2. Symptom measures. We assessed emotion regulation skills using the Emotion Regulation Skills Questionnaire (ERSQ-ES; Ebert et al., 2013) across six pertinent emotion-specific domains and nine skill-specific regulation strategies. Following Ebert et al. (2013), we used the mean score of all subscales (except positive emotion regulation skills) to measure emotion regulation skills. Internal consistency was high across time points (α = 0.952–0.976).

2.4. Secondary outcome measures

2.4.1. Symptom measures

We assessed depression via the Center for Epidemiologic Studies Depression Scale (CES—D, Hautzinger and Bailer, 1993) and stress via the Perceived Stress Scale–10 (PSS–10, Schneider et al., 2020). Internal consistencies were high across time points (CED—D: α = 0.89–0.91; PSS-10: α = 0.82–0.84).

[1] Stimulus material, anonymized data, code and detailed results are available through the OSF repository at: https://osf.io/7hxd8/

2.4.2. Anagram stressor task

To measure stress reactivity, we employed a computerized anagram task (Becker et al., 2016). Participants were requested to solve 20 anagrams, i.e., letter strings. Participants were instructed that all anagrams are solvable; however, in reality, seven anagrams were solvable, while 13 were unsolvable. Upon completion, and irrespective of the participant's performance, feedback was given that the performance was unusually low (i.e., that 87% of participants had performed better).

2.4.3. Mood scale

To assess state affect before and after the Anagram task, we used the six-item mood scale for the Anagram task (Becker et al., 2016), with three items reflecting a depression-related (e.g., sadness) and three items reflecting a stress-related dimension (e.g., tension). Internal consistencies across subscales and time points ranged from α = 0.60–0.80.

2.4.4. Usability and treatment satisfaction

The 10-item System Usability Scale (SUS; Brooke, 1996) was used to capture app usability. Total scores were determined by multiplying sum scores by factor 2.5, eventually averaging it across all participants, to indicate a percentage of user satisfaction. Internal consistency on this scale was acceptable (α = 0.63).

2.5. Interventions

2.5.1. Active intervention (Mindgames; including CBM-ART)

In the active intervention, participants received seven daily modules, with each module incorporating one emotion regulation skill (e.g., “nonjudgmental awareness of emotions”; Böhme and Berking, 2021). Modules contained a psychoeducational text, a quiz and a single session of CBM-ART. Within modules, participants first saw psychoeducational texts that described the background and implementation of the emotion regulation skill. Participants then completed a quiz consisting of three to six single-choice questions, each accompanied by four answers. Quizzes were considered complete after all questions had been answered correctly, with participants receiving reward points. When responding incorrectly, participants had to complete the quiz again. During CBM-ART, they received 28 randomized statements embedded in a contextual picture to enhance imagery of the verbal statement (see Mao et al., 2023). Statement-picture combinations were presented centrally against a black background, with a bar indicating participants' training score on the upper left side of the screen. Participants were asked to judge if statements were functional (i.e., “helpful”). Functional stimuli were to be pulled to the bottom of the smartphone screen, with picture sizes increasing, and dysfunctional stimuli were to be pushed to the top of the smartphone screen, with picture sizes decreasing. Participants received decision-contingent feedback (100% contingency). For correct judgements (i.e., pulling functional statements and pushing dysfunctional statements), participants received rewarding feedback (i.e., smiling face, text: “Reacted correctly”, points being added to their total score), and for incorrect judgements, they received punishing feedback (i.e., sad face, text: “Reacted incorrectly”, points being deducted from their total score, vibration of the smartphone).

All modules could be completed independently from each other, including possible repetitions to receive more points. The individual total score was displayed throughout application use. Modules were considered complete after completion of each subsection. Participants received access to the next chronological module on the following day.

2.5.2. Control condition (CC; Emo Shape)

To differentiate relevant mechanisms related to emotion regulation, we tailored the active control condition to mirror expectancy and practice effects of the CBM-ART (Blackwell et al., 2017). Thus, in the CC, participants received the identical, seven-day protocol, entailing a psychoeducational text, quiz, and sham training session per module. Structures, features and feedback mechanisms were identical to the

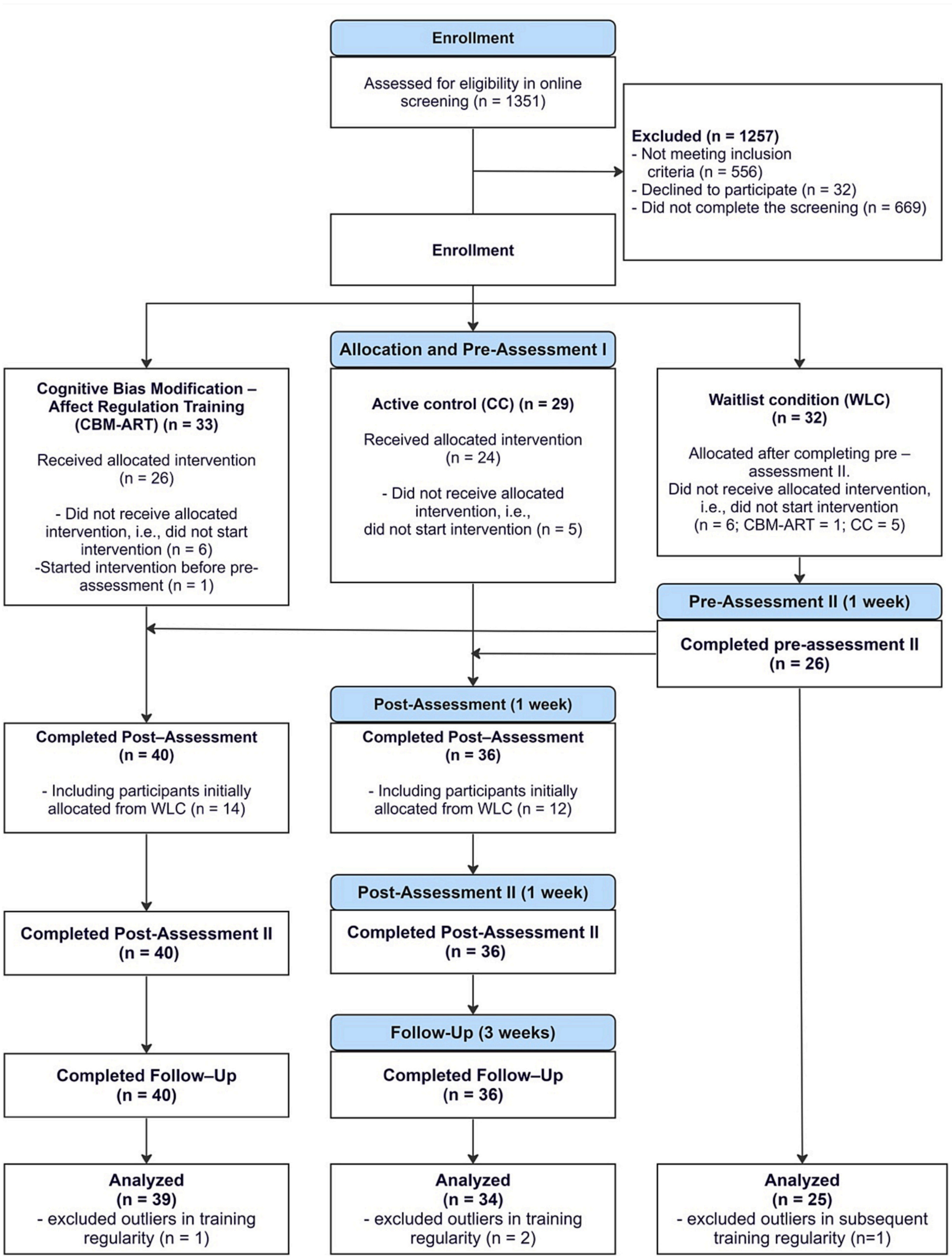

Fig. 2. CONSORT flow diagram.
Notes. Flow of participants through phases of study according to the CONSORT guidelines.

active intervention; however, content pertained to the influence of geometrical shapes on emotions.

In psychoeducational texts, participants received information about the emotional effects of geometric shapes (e.g., angular-shaped forms evoke negative, and circular shapes evoke positive emotions [Aronoff, 2006]) and their potential benefits for regulating emotions. Psychoeducation was based on the extant literature, but findings were overemphasized to induce comparable expectancy effects. Quizzes covered comprehension questions regarding psychoeducation.

The sham training consisted of 28 randomized trials in which participants completed a concurrent swiping task. All shapes (i.e., circles, squares, or triangles; depicted in yellow, blue, or red) were displayed centrally against a black background. Participants were instructed to pull yellow circles and push all other combinations.

2.5.3. Waitlist condition (WLC)

The WLC underwent a waiting period of one week before being randomized into CBM-ART or CC.

2.6. Procedure

Fig. 1 depicts the study procedure, including the crossover design and randomization procedure. Overall, participants completed all interventions using a dedicated application (Android system version 8 or higher). Participants underwent pre- and post-assessment as video-based online sessions, with sessions being guided by research assistants. Research assistants were blind against active conditions; however, due to the crossover design, they could deduce if participants had undergone the WLC. Training and follow-up assessments were conducted as unguided online sessions.

Throughout CBM-ART and CC, participants were instructed to complete as many modules and sessions as possible (i.e., with a minimum of one per day), receiving a daily notification at 12 pm to open their application. Upon study completion, participants were debriefed, obtaining time-contingent course credit and the chance to win Amazon vouchers.

2.7. Statistical analysis

Following the crossover trial design, data of participants from the WLC was collected across two time periods. That is, during the WLC period, Pre-I and Pre-II-assessment served as pre- and post-assessments for the waiting period, and the Pre-II assessment served as pre-assessment for the subsequent active condition (CBM-ART or CC, as per randomization, see Fig. 1).

Overall, statistical analyses were performed on the per-protocol and intention-to-treat sample (with the latter including the $n = 4$ cases excluded due to training irregularities), treating all missing data as missing at random. To test hypotheses, we computed mixed models using R (R Core Team, 2021) and the R package "lme4" (Bates et al., 2015). For self-report data, total scores were predicted assuming a subject-specific random intercept. For interpretation bias data, a generalized mixed model was fitted, using the logit as link function, specifying an underlying crossed random factors structure with random intercepts and slopes in item-specific valence and person-specific time effects. The factors *time* (i.e., time points) and *group* (i.e., three conditions) were added as predictors. Models were fitted using restricted maximum likelihood (REML) estimation. Effects and specific parameters within the binary outcome models were tested via Wald χ^2 and Wald Z tests, respectively. Omnibus F-Tests were performed to check for interaction effects and main effects. Further, semi-partial R-squared statistics ($R^2_{\beta*}$) for fixed effects were calculated using the R package "r2glmm" (Jaeger et al., 2017). For interactions, between-group contrasts at each time point and effect sizes were derived from mixed models via the R package "emmeans" (Lenth et al., 2018). Effect sizes were estimated using Cohen's *d*, dividing estimated mean differences derived from the mixed models by observed SD. For between-group effect sizes, we used the SD of change scores, and for within-group effect sizes, we used the pooled SD of scores at baseline and the respective time point. The Hedges' *g* correction for sample size was applied, and 95% CIs were calculated using the R package "MBESS" (Kelley, 2022). For binary outcomes, odds ratios (OR) were used as effect size measures for main, and ratio of odds ratios (ORR) for interactional effects. All statistical tests were 2-tailed using $p < .05$. For multiple pairwise comparisons, Bonferroni correction was applied, dividing the *p*-value by the respective number of tests.

3. Results

Sociodemographic and psychometric properties of this sample are shown in Tables 1 and 2. Notably, groups did not differ on all baseline variables (all *ps* > .11).

3.1. Session compliance and dropout

No dropouts were recorded. Overall, completers in CBM-ART and CC did not differ in average session attendance (see Table 1).

3.2. Per-protocol analysis[2]: Primary outcome measures

Table S1 (see Supplementary Material) contains between-group effect sizes across all outcome variables.

3.2.1. Interpretation bias

Means and standard deviations for SWAP endorsement rates are shown in Table 2. Pertinent group interactions are depicted in Fig. 3. As the three-way interaction (*valence x time x group*) was significant, $\chi^2(3) = 115.57, p < .001$, we fitted separate models for endorsing positive and negative interpretations.

For negative endorsements, we found a significant *time x group* interaction, $\chi^2(3) = 11.89, p = .008$, and a significant main effect of *time*, $\chi^2(2) = 75.80, p < .001$. Odds ratio between pre- and post-assessment for CBM-ART was significantly smaller vs. CC, *ORR* = 0.659 (95% CI 0.44–0.98), $Z = -2.06$, $p = .039$, and vs. WLC, *ORR* = 0.482 (95% CI 0.31–0.74), $Z = -3.31$, $p < .001$.Within-group odds were significantly smaller at post-assessment than at pre-assessment for CBM-ART, *OR* =

Table 1
Baseline demographics.

	CBM-ART (n = 39) M (SD)/n (%)	CC (n = 34) M (SD)/n (%)	WLC (n = 25) M (SD)/n (%)	Total (N = 98) M (SD)/n (%)
Age	22.95 (4.35)	21.41 (2.89)	22.28 (3.20)	22.24 (3.64)
Gender				
Male	13 (33.3%)	8 (23.5%)	7 (28.0%)	28 (28.6%)
Female	25 (64.1%)	26 (76.5%)	18 (72.0%)	69 (70.4%)
Diverse	1 (2.6%)	0 (0.0%)	0 (0.0%)	1 (1.0%)
Number of training sessions				
Swiping	11.40 (8.42)	16.50 (13.70)		13.80 (11.40)
Quiz	5.46 (2.32)	5.62 (1.56)		5.53 (1.99)

Notes. CBM-ART=Cognitive Bias Modification–Affect Regulation Training, CC=Control Condition, WLC=Waitlist Condition.

[2] We repeated analyses with the intention-to-treat sample (i.e., including the $n = 4$ cases excluded due to substantial training irregularities). The pattern of results did not differ from per-protocol analyses (see OSF repository for detailed results).

Table 2
Effects of conditions on interpretation bias and symptoms.

	Pre-assessment			Post-assessment (+1 week)			Post-II (+2 weeks)		Follow-up (+4 weeks)	
	CBM-ART	CC	WLC	CBM-ART	CC	WLC	CBM-ART	CC	CBM-ART	CC
Positive endorsement	$n = 39$[a]	$n = 34$[a]	$n = 25$	$n = 37$[a,c]	$n = 33$[a,b]	$n = 25$			$n = 38$[a,b]	$n = 33$[a,b]
M (SD)	69.36 (17.93)	63.38 (18.87)	60.25 (17.23)	81.79 (12.86)	69.92 (16.90)	61.90 (21.12)			78.49 (18.28)	73.71 (14.75)
OR [95% CI]				2.40 [1.82;3.17]	1.49 [1.12;1.97]	1.09 [0.79;1.50]			2.04 [1.47;2.84]	1.90 [1.35;2.68]
Negative endorsement	$n = 39$[a]	$n = 34$[a]	$n = 25$	$n = 37$[a,c]	$n = 33$[a,b]	$n = 25$			$n = 38$[a,b]	$n = 33$[a,b]
M (SD)	44.58 (20.62)	50.70 (18.55)	53.70 (20.39)	27.26 (19.97)	38.37 (20.19)	48.50 (25.46)			27.70 (20.13)	33.94 (19.73)
OR [95% CI]				0.35 [0.25;0.49]	0.53 [0.37;0.75]	0.72 [0.48;1.08]			0.34 [0.25;0.47]	0.39 [0.28;0.55]
PSS-10	$n = 39$[a]	$n = 33$[a,b]	$n = 25$	$n = 37$[a,c]	$n = 34$[a]	$n = 25$	$n = 39$[a]	$n = 34$[a]	$n = 39$[a]	$n = 34$[a]
M (SD)	31.95 (7.03)	32.42 (5.39)	32.00 (7.17)	26.59 (5.26)	27.24 (5.83)	31.52 (6.84)	27.03 (6.01)	28.32 (6.28)	25.59 (6.24)	26.32 (5.79)
d [95% CI]				−0.87 [−1.26;-0.50]	−0.91 [−1.36;-0.48]	−0.07 [−0.35;0.21]	−0.74 [−1.11;-0.38]	−0.67 [−1.12;-0.25]	−0.94 [−1.37;-0.53]	−1.07 [−1.57;-0.61]
CES-D	$n = 39$[a]	$n = 33$[a,b]	$n = 25$			$n = 25$	$n = 39$[a]	$n = 34$[a]	$n = 39$[a]	$n = 34$[a]
M (SD)	23.36 (10.74)	23.18 (10.35)	25.32 (9.32)			23.68 (11.86)	17.62 (8.56)	20.15 (11.52)	15.49 (9.32)	17.06 (10.88)
d [95% CI]						−0.15 [−0.45;0.15]	−0.58 [−0.95;-0.22]	−0.26 [−0.53;0.00]	−0.77 [−1.18;-0.38]	−0.55 [−0.86;-0.27]
ERSQ-ES	$n = 39$[a]	$n = 33$[a,b]	$n = 25$			$n = 25$	$n = 39$[a]	$n = 34$[a]	$n = 39$[a]	$n = 34$[a]
M (SD)	2.37 (0.54)	2.11 (0.53)	2.30 (0.64)			2.34 (0.70)	2.64 (0.46)	2.41 (0.63)	2.68 (0.55)	2.54 (0.67)
d [95% CI]						0.06 [−0.26;0.38]	0.52 [0.21;0.85]	0.48 [0.17;0.82]	0.54 [0.20;0.91]	0.67 [0.33;1.03]

Notes. CBM-ART=Cognitive Bias Modification–Affect Regulation Training, CC=Control Condition, CES-D=Center for Epidemiologic Studies Depression Scale, *d* = Cohen's *d* (within-group effects; see Table S1 in Supplementary Materials for between-group effects), ERSQ-ES = Emotion Regulation Skills Questionnaire-Emotion Specific, *OR* = Odds ratio, PSS-10 = Perceived Stress Scale-10, WLC=Waitlist Condition.

[a] Sample including crossover participants from WLC.
[b] Due to technical difficulties, $n = 1$ entry was not recorded.
[c] Due to technical difficulties, $n = 2$ entries were not recorded.

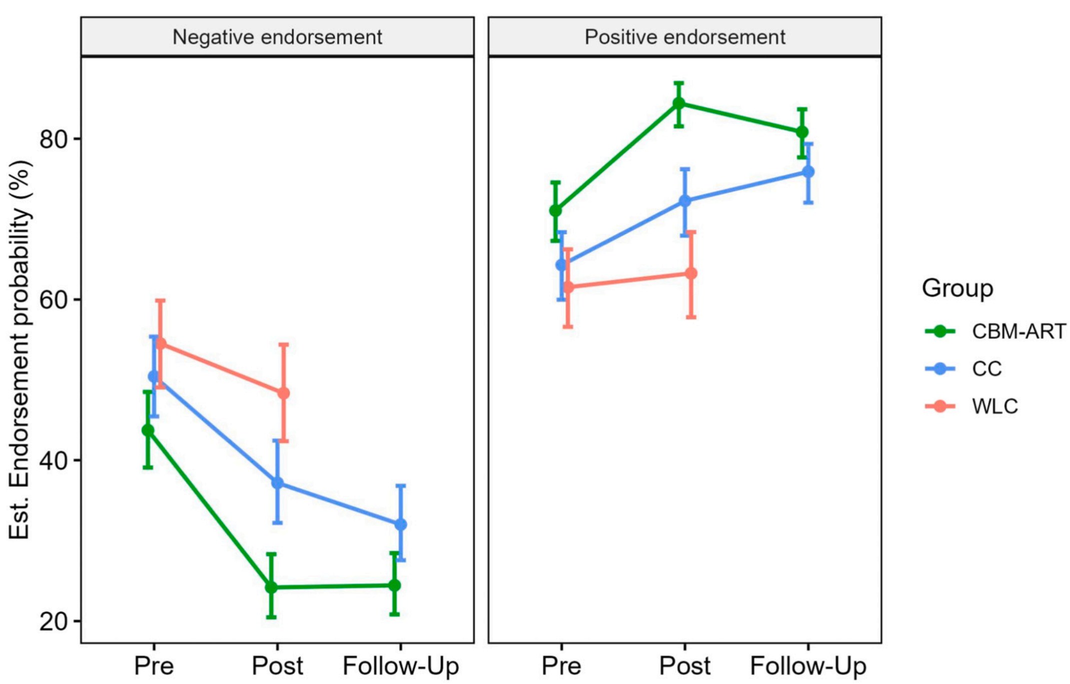

Fig. 3. Estimated endorsement probabilities for valent interpretations on the SWAP.
Notes. Estimated mean values derived from Generalized Linear Mixed Models. Error bars indicate the 95% CI for within-group comparisons. CBM-ART=Cognitive Bias Modification-Affect Regulation Training, CC=Control Condition, WLC=Wait List Condition.

0.348 (95% CI 0.25–0.49), $Z = -7.51$, $p < .001$, for CC, $OR = 0.528$ (95% CI 0.37–0.75), $Z = -4.37$, $p < .001$, but not for the WLC, $OR = 0.722$ (95% CI 0.48–1.08), $Z = -1.92$, $p = .166$. That is, the probability of endorsing negative interpretations decreased for CBM-ART and CC, indicating reduction in negative interpretation bias. This reduction was differentially greater within CBM-ART.

For positive endorsements, we found a significant *time x group* interaction; $\chi^2(3) = 23.93$, $p < .001$, and a main effect of *time*; $\chi^2(2) = 58.51$, $p < .001$. Odds ratios increased from pre- to post-assessment within CBM-ART, vs. CC, $ORR = 1.615$ (95% CI 1.17–2.23), $Z = 2.92$, $p = .004$, and WLC, $ORR = 2.211$ (95% CI 1.56–3.13), $Z = 4.48$, $p < .001$. Further, odds significantly increased within CBM-ART, $OR = 2.404$ (95% CI 1.82–3.17), $Z = 7.59$, $p < .001$, within CC, $OR = 1.488$ (95% CI 1.12–1.97), $Z = 3.38$, $p = .002$, but not WLC, $OR = 1.087$ (95% CI 0.79–1.50), $Z = 0.62$, $p = .999$. That is, probabilities for endorsing positive interpretations (i.e., positive interpretation bias) increased in CBM-ART and CC, but not WLC, with differentially greater increases in CBM-ART.

3.2.2. Emotion regulation skills

Regarding ERSQ-ES scores, we found no significant two-way interaction, $F(3,165) = 1.79$, $p = .152$, $R^2_{\beta*} = 0.032$, but a significant main effect of *time*, $F(2,165) = 19.09$, $p < .001$, $R^2_{\beta*} = 0.177$, indicating that ERSQ-ES scores increased significantly from pre- to post-assessment for CBM-ART, $b = 0.27$ (95% CI 0.08–0.46) and CC, $b = 0.29$ (95% CI 0.08–0.49), but not for WLC $b = 0.04$ (95%CI -0.19–0.28). Of note, in the absence of a significant two-way interaction, the size of these changes did not differ across groups.

3.3. Secondary outcome measures

3.3.1. Stress

Regarding PSS-10 scores, we found a significant *group x time* interaction, $F(3,164) = 3.83$, $p = .011$, $R^2_{\beta*} = 0.066$, and a main effect of *time*, $F(2,164) = 37.11$, $p < .001$, $R^2_{\beta*} = 0.288$. Specifically, there was a greater reduction in perceived stress from pre- to post-assessment in CBM-ART, vs. WLC, $t(164) = 3.13$, $p = .002$, $d = -0.86$ (95% CI -1.40–-0.34), but not vs. CC, $t(164) = 0.19$, $p = .851$, $d = -0.04$ (95% CI -0.51–0.42). Within-group analyses revealed a significant pre-post reduction for CBM-ART, $b = -5.49$, (95% CI -7.94–-3.04), and CC, $b = -5.21$, (95% CI -7.81–-2.61), but not WLC, $b = -0.48$ (95% CI -3.48–2.52).

3.3.2. Depression

Regarding CES-D scores, the two-way interaction was non-significant, $F(3,165) = 1.17$, $p = .324$, $R^2_{\beta*} = 0.021$. However, there was a significant main effect of *time*, $F(2,165) = 21.10$, $p < .001$, $R^2_{\beta*} = 0.191$, indicating a within-group reduction from pre- to post-assessment for CBM-ART, $b = -5.74$ (95% CI -9.30–-2.19), but not CC, $b = -2.91$ (95% CI -6.75–0.94), or WLC, $b = -1.64$ (95% CI -6.08–2.80). Nonetheless, the lack of *group x time* interaction shows that the magnitude of these changes did not differ between groups.

3.3.3. Stress reactivity

Regarding mood subscales (see Table 3), there was no *time x group* interaction (depression-related mood: $F(1,68) = 0.27$, $p = .605$, $R^2_{\beta*}$=. 004; stress-related mood: $F(1,68) = 0.03$, $p = .855$, $R^2_{\beta*} = 0.00$), but significant main effects of *time*, indicating concurrent pre-post increases in stress- and depression-related mood after the stressor in all groups (depression-related mood: $F(1,68) = 22.56$, $p < .001$, $R^2_{\beta*} = 0.259$; stress-related mood: $F(1,68) = 14.13$, $p < .001$, $R^2_{\beta*} = 0.176$).

3.4. Follow-up effects

For endorsement rates, within-group effects from pre-assessment to follow-up were maintained for CBM-ART and CC (see Table 2). Yet, between-group differences (for CBM-ART vs. CC) from post-assessment were no longer present at follow-up (negative endorsements: $ORR = 0.877$ (95% CI 0.60–1.13), $Z = -0.67$, $p = .499$; positive endorsements: $ORR = 1.073$ (95% CI 0.73–1.58), $Z = 0.36$, $p = .721$).

For symptom scores, within-group changes were maintained across measures, i.e., for the ERSQ-ES (CBM-ART: $b = 0.30$ (95% CI 0.11–0.49; CC: $b = 0.42$ (95% CI 0.21–0.62), the PSS-10 (CBM-ART: $b = -6.36$ (95% CI -8.76– -4.00); CC $b = -6.13$ (95% CI -8.72– -3.53)) and the CES-D (CBM-ART, $b = -7.89$ (95% CI -11.43– -4.32); CC, $b = -5.99$ (95% CI -9.84–-2.15)).

Table 3
Effects of conditions on stress reactivity.

	Before stressor		After stressor	
	CBM-ART	CC	CBM-ART	CC
Depressive mood	n=34[a]	n = 33[b]	n=34[a]	n = 33[b]
M (SD)	8.32 (1.45)	8.48 (2.59)	9.74 (2.61)	10.20 (2.74)
d [95% CI]			0.65 [0.25;1.08]	0.64 [0.31;1.00]
Stress-related mood	n=34[a]	n = 33[b]	n=34[a]	n = 33[b]
M (SD)	7.26 (2.18)	8.00 (2.78)	8.74 (2.91)	9.33 (2.91)
d [95% CI]			0.56 [0.17;0.97]	0.46 [0.12;0.81]

Notes. SDs in parentheses. CBM-ART=Cognitive Bias Modification-Affect Regulation Training, CC=Control Condition, d = Cohen's d (within-group effects; see Table S1 in Supplementary Materials for between-group effects).
[a] Due to technical difficulties, $n = 5$ entries were not recorded.
[b] Due to technical difficulties, $n = 1$ entry was not recorded.

3.5. Usability and treatment satisfaction

Overall, CBM-ART ($M = 85.95\%$, $SD = 8.49$) and CC ($M = 86.03\%$, $SD = 7.21$) received excellent satisfaction scores and good usability ratings (see Table S2 in Supplementary Materials) that were comparable to other app-based interventions (e.g., see Kuck et al., 2022).

4. Discussion

The present study aimed at expanding previous findings on the beneficial effects of smartphone-based affect regulation training (ART) by investigating the efficacy of a novel integrated CBM protocol (CBM-ART, as part of the *Mindgames* module in the ART-App) targeting post-hoc appraisal biases of emotions in elevated stress. To this end, we examined both near- and far-transfer effects on cognitive biases, psychopathology and stress reactivity, while also investigating acceptability and usability.

Findings revealed large within-group effects of CBM-ART on both negative and positive interpretation bias, outperforming the CC and WLC. Additionally, both CBM-ART and CC led to small to moderate within-group effects for perceived stress, depression, and emotion regulation skills. Importantly, these near-transfer effects were maintained at follow-up. Of note, significant between-group differences in symptom scores for active conditions only emerged for stress symptoms and were small in size (see Table S1 in Supplementary Materials). Last, we did not find differential far transfer effects for stress reactivity during stressor exposure. Overall, these results provide initial evidence for the efficacy of CBM-ART in reducing maladaptive interpretation biases and associated psychopathology, thus corroborating model assumptions on the association between emotion regulation and psychopathology (e.g., Joormann and Gotlib, 2010). Overall, small between-group effects between digital interventions and matched control conditions for depression and anxiety have likewise been demonstrated in current meta-analyses (e.g., Linardon et al., 2019). Relatedly, within-group effect sizes in this study overall mirror meta-analytic findings for transfer effects in CBM research (e.g., Fodor et al., 2020; Martinelli et al., 2022), although comparability remains limited due to a relative scarcity of similar placebo control conditions and training variants within the literature. Moreover, these meta-analyses commonly yield inconsistent to absent effects of CBM on stress reactivity, which may be due to numerous reasons, including mismatch between the trained material and the stressor paradigm (see Dietel et al., 2018). To illustrate, while CBM-ART trains overarching emotion regulation, the anagram task, as used in this study, induces performance-related stress, thereby neglecting other trained situational triggers. Thus, future studies should reinvestigate far transfer effects using more global stress exposure tasks (e.g., the Trier Social Stress Test; Kirschbaum et al., 1993) or ecological, personalized stress indices (e.g., via Ecological Momentary Assessment).

Interestingly, as is common in CBM research (e.g., Fodor et al., 2020; Martinelli et al., 2022), this study revealed attenuated beneficial effects on most outcome variables in the CC. When considering the setup of the active control condition, several explanations may account for these effects. First, psychoeducation about emotions may have contributed to beneficial effects by stimulating increased awareness and self-monitoring (Donker et al., 2009). Second, the geometrical swiping task may have helped to strengthen emotion regulation, i.e., through engaging with a cognitive task, a technique used in skill training in dialectical behavior therapy (Linehan, 2014). Relatedly, the task's gamified setup in which participants are asked to categorize stimuli as fast as possible may carry attributes of a cognitive control training, thus potentially enhancing cognitive flexibility. Indeed, prior research demonstrated the benefits of cognitive control training in depression (Koster et al., 2017), although effects on emotion regulation have so far been limited to lowering rumination (Hoorelbeke et al., 2016). Overall, both active conditions received equal satisfaction ratings, which might indicate similar face validity. Moreover, these similar ratings highlight that multiple features inherent to integrated CBM rationales, e.g., integration with psychoeducation, gamification and feedback, exert an important influence on training benefits. Given these possibilities, future mechanistic studies should disentangle the underlying mechanisms driving change in emotion regulation through CBM protocols.

Overall, both CBM-ART and CC were deemed usable and acceptable, exceeding satisfaction ratings of 85%. Of note, both applications featured gamification elements (e.g., modules, scoring systems, multichannel feedback) to strengthen user engagement, which may help explain these results. While gamification is critical for naturalistic implementation, it is also paramount for prospective adoption in younger users displaying deficits in emotion regulation. Importantly, youth has been demonstrated to benefit from CBM with regard to bias indices; however, showing no, and thus improvable effects for mental health outcomes (Cristea et al., 2015; Sicouri et al., 2023). Additionally, children and adolescents typically exhibit low adherence in digital programs (Hollis et al., 2016). As a possible solution, recent research indicates improved user adherence and engagement for gamified CBM in children (e.g., Salemink et al., 2022), thus yielding avenues to further enhance gamification (i.e., through adaptive individual levels) within *Mindgames* when implementing it in other populations, e.g., youth.

This study has some limitations. First, due to organizational and time restrictions, this study could not be preregistered prior to data collection, which is a limitation with regards to Open Science practice. Second, this study was conducted in undergraduate students exhibiting elevated stress, and administered solely through Android devices, thus limiting generalizability beyond these constraints. Additionally, while this study was powered for medium to large between-group effects, as per more conservative estimations (see Cohen, 2013), power was insufficient for the detection of smaller effects. Hence, taken together, future research should evaluate interventional efficacy in larger, more diverse samples and alternative psychopathology (e.g., anxiety and depression), further testing transfer to iOS and integration of CBM-ART with other intervention programs. Third, this CBM program specifically targeted post-hoc appraisal biases of emotions and emotion regulation. However, as emotion regulation entails more steps (i.e., attention allocation), future research might investigate the combined efficacy of CBM-ART with other treatment modules tailored to address these steps (e.g., Cognitive Bias Modification for Attention). Fourth, this study examined the efficacy and acceptability of CBM-ART within a randomized-controlled crossover trial, including a short-term follow-up. Thus, future studies might gauge more long-term effects of CBM-ART and its implementation within naturalistic settings, i.e., when delivered through app stores. In this regard, testing against alternative control conditions, e.g., comparing against alternative digital or face-to-face interventions for emotion regulation, as well as examining currently unexplored adverse effects (e.g., Rozental et al., 2018; Ma et al., 2020) appear useful to determine clinical utility. Last, this study tested CBM-ART and CC as integrated versions featuring psychoeducation and quizzes, with these components thus partially driving effects. To examine more mechanistic CBM-related effects with regard to post-hoc emotional appraisal, future studies might investigate the efficacy of standalone CBM-ART and, consistently, vary training-related parameters (e.g., investigating effects of different reinforcement contingencies).

Overall, this was the first study to demonstrate beneficial effects of a novel, smartphone-based CBM paradigm to enhance emotion regulation in elevated stress. While results indicate beneficial effects on interpretation biases and psychopathology, as well as good acceptability, the active control condition showed attenuated changes, thus highlighting a need to further study underlying mechanisms driving these effects. Nonetheless, as smartphone interventions for emotion regulation have gained momentum (Bettis et al., 2021), CBM-ART holds promise to provide a transdiagnostic, accessible, low-threshold tool that may be readily implemented within various prevention and intervention settings.

Declaration of competing interest

None. This study received no external funding.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.invent.2024.100719.

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