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Imager—A mobile health mental imagery-based ecological momentary intervention targeting reward sensitivity: A randomized controlled trial

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Abstract

Robust reward sensitivity may help preserve mental well-being in the face of adversity and has been proposed as a key stress resilience factor. Here, we present a mobile health application, "Imager," which targets reward sensitivity by training individuals to create mental images of future rewarding experiences. We conducted a two-arm randomized controlled trial with 95 participants screened for reward sensitivity. Participants in the intervention group received an ecological momentary intervention—Imager, which encouraged participants to create mental images of rewarding events for 1 week. The control group participants received only ecological momentary assessment, without the instruction to generate mental images. Adherence to Imager was high; participants in the intervention group engaged in 88% of the planned activities. In the follow-up assessment, the intervention group reported less mental health symptoms, mainly in depression ($\beta = -0.34$, $df = 93$, $p = .004$) and less

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perceived stress ($\beta = -0.18$, $df = 93$, $p = .035$), than control group participants and compared with the baseline assessment. Our results show the positive effects of Imager on mental health symptoms. The encouraging effects of the app on mental health outcomes may lead to greater use of ecological momentary interventions in the clinical preventive practice of affective disorders.

KEYWORDS
ecological momentary intervention, mental imagery, mHealth, mobile app, resilience, reward sensitivity

INTRODUCTION

Stress resilience is a key concept during times of enhanced stressor exposure, which currently include, for instance, the recent COVID-19 pandemic and destabilized political situation in Europe. Such adversities generally increase stress in most of those exposed, especially in diathetic populations (Broerman, 2017). Much research has focused on identifying factors and mechanisms contributing to resilience—that is, to the maintenance or quick recovery of mental well-being during and after adversity (Kalisch et al., 2017, 2019; Pearman et al., 2021).

Recently, reward sensitivity, defined as the ability to experience pleasure in the anticipation and presence of reward-related stimuli (such as, for instance, food, social relationships, achievements, and hobbies) (Gray & Gelder, 1987; Taubitz et al., 2015), has been identified as a potential key resilience factor (Geschwind et al., 2010; Taubitz et al., 2015). Studies suggest that greater reward sensitivity is associated with higher levels of positive affect following stressor exposure (Corral-Frías et al., 2016) and high reward experience in daily life preserves positive mental health (Geschwind et al., 2010). Response to rewards predicts adaptive functioning across various domains, for instance, decreased internalizing, externalizing, and use of suppression, increased use of reappraisal, and increased well-being; what is more, it may be protective against dysfunctional impulsive behavior such as pursuing short-term rewards while ignoring long-term negative consequences (Taubitz et al., 2015). Interestingly, reward sensitivity may not be a stable personality trait; it can vary across contexts, leading to fluctuations in reward-seeking behavior (Neuser et al., 2019, 2020).

Researchers have assigned a critical role to reward sensitivity in predicting the outcomes of psychotherapy in the context of stress-related disorder (Clark et al., 2015; Reiter et al., 2021), meaning that reward sensitivity is a promising target for the promotion of mental health, which includes not only the absence (or treatment) of mental health disorders but also the state in which an individual can cope with the normal stresses of life, can work productively, and make a contribution to their community (World Health Organization, 2023).

Mental imagery, often referred to as "seeing in the mind's eye," is a form of perception without external stimuli and has been utilized in reward-related exercises (Ji et al., 2019). A variety of mechanisms support the role of mental imagery in enhancing reward sensitivity and resilience. Neurobiologically, it activates the brain's reward system, heightening reward sensitivity over time (Costa et al., 2010). Cognitively, positive imagery challenges negative future beliefs, fostering optimism and reinforcing positive thinking (Bennetts et al., 2020). Emotionally, it boosts motivation by encouraging goal pursuit and engagement in favorable outcomes (Renner et al., 2019). Behaviorally, it promotes approach behaviors, enhancing involvement in positive experiences and achievements (Renner et al., 2017, 2021). Linke and Wessa (2017) conducted a study in which they administered a mental imagery intervention via the Internet and found that the intervention comprising imaging positive emotions, affirmative thoughts, and pleasurable sensations associated with positive stimuli, delivered in eight 10 min sessions to healthy volunteers, was effective in enhancing reward sensitivity and reducing depressive symptoms ($\eta_p^2 = 0.16$). In another study, Renner et al. (2019) found that participants who engaged in a 1 week mental imagery training, which composed of audio recordings and photos of positively ending everyday situations, reported higher levels of, for instance, anticipated pleasure and anticipated reward for planned activities. These mechanisms suggest the potential of mental imagery as an intervention, especially in the context of ecological momentary interventions (EMIs) within mobile health (mHealth) apps, an area yet to be explored.

EMIs are mostly delivered as smartphone-based mobile apps that individuals can use during their everyday lives and in their natural settings, rendering EMIs scalable and easily accessible for broad groups of recipients (Heron & Smyth, 2010). Standalone mHealth EMI apps have been effective in reducing various mental health symptoms, for instance, depression, anxiety, eating disorders, and more (Loo Gee et al., 2016; Versluis et al., 2016). Using EMI for mental imagery interventions offers advantages over broader online platforms, providing naturalistic accessibility in participants' daily lives. This enhances intervention relevance and effectiveness. EMI, coupled with ecological momentary assessment (EMA), offers an ecologically valid approach for deeper insights into mental health dynamics and intervention outcomes. However, the precise and mechanistic targeting of the particular psychological processes that are thought to be engaged via such interventions, such as reward sensitivity, has received little attention. Because EMIs often engage more than one mechanism or therapeutic strategy to change more than one mental health symptom, it can be difficult to distinguish which component of an intervention is effective (Marciniak et al., 2020) and thus what causes changes in EMI users' mental health, beliefs, or behavior.

The current study expands on recent empirical findings that identify reward sensitivity as a potential resilience factor and utilizes the role of mental imagery in increasing reward sensitivity (Renner et al., 2021). We investigate the feasibility, efficacy, and target mechanism engagement (reward sensitivity) of Imager, an mHealth EMI aimed at increasing stress resilience using mental imagery in young, healthy adults screened for reward sensitivity. Assessing the feasibility and efficacy of EMIs before widespread implementation is vital for real-life user support and advancing science-based practices. It informs resource allocation and identifies and mitigates potential risks to participants in the intervention. To test Imager's feasibility, we examined adherence to the EMI and user experience ratings. To assess efficacy, we tested whether the intervention group (IG) using Imager EMI experienced greater reductions in symptoms of depression, anxiety, and perceived stress than the active control group (CG) using EMA only. This choice of control condition enabled us to assess the changes caused only by the EMI part of the app. Finally, for target mechanism engagement, we tested whether changes in reward sensitivity were greater in the IG than in the CG.

METHODS

Study design

We conducted a two-arm randomized controlled trial with 95 healthy (i.e. without a diagnosis of mental illness reported in the screening) student participants with lowered reward sensitivity scores (i.e. five or more points in the [reversed] reward responsiveness subscale of Behavioral Avoidance/Inhibition Scales [BIS/BAS]). Allocation to CG or IG was conducted using a block $n = 5$ algorithm generated by an independent researcher. Fifty-one participants in the IG received 10 EMA prompts, of which three were combined with an instruction to engage in mental imagery training for seven consecutive days (see Figure 1). The number of training days was decided based on previous research on mental imagery delivered via internet-based tools, which varied from 4 to 12 sessions, depending on the study (Blackwell et al., 2015; Linke & Wessa, 2017; Renner et al., 2017). The CG received 10 EMA prompts per day, without the option of mental imagery training. Use of such control condition is also an established practice in testing effects of EMI on mental health (e.g. Hur et al., 2018; Versluis et al., 2018).

Ethics approval

The Ethics Committee of the Faculty of Arts and Social Sciences of the University of Zurich approved the study proposal (approval #20.6.11). The clinical trials identifier is NCT05623826. The study was registered retrospectively.

Stakeholders' involvement

Our study's stakeholders, students from the greater Zurich area, actively participated in the development of the EMI. We provided them with an overview of potential solutions and the EMI's content, which they found interesting and easily understandable. They evaluated both technical aspects and the potential psychological impact. A key suggestion they unanimously supported was adding a user-triggered intervention button for flexibility. Notifications were deemed essential, as they enhance engagement. However, incorporating gamification

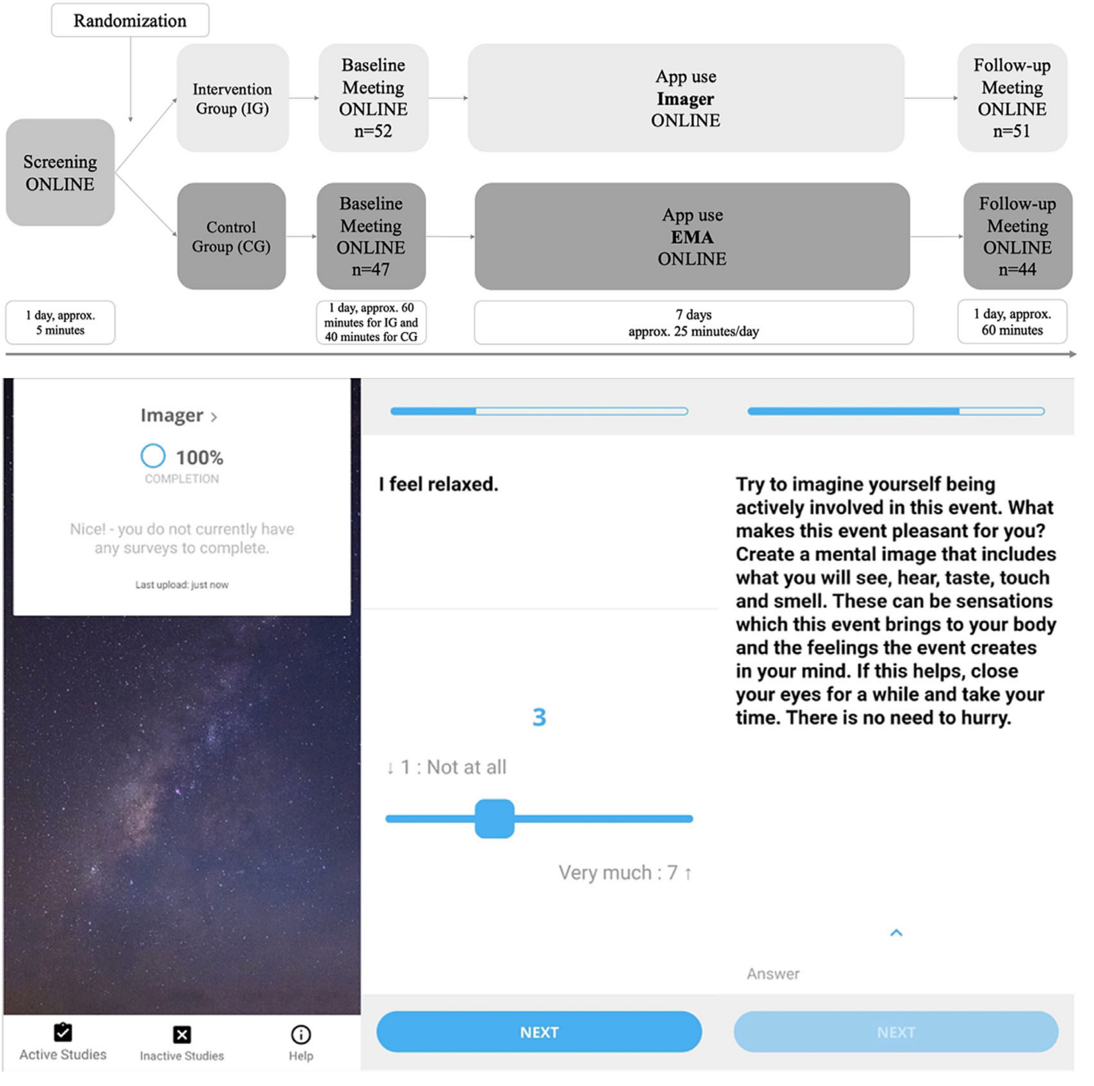

FIGURE 1 Study design and example screens from Imager. EMA, ecological momentary assessment.

received mixed feedback due to concerns about distraction and addiction. Other options like photos and voicemails were rated as unnecessary or problematic due to privacy concerns. Stakeholders' involvement was critical in shaping the app, ensuring usability, and addressing concerns for an effective psychological intervention tool.

Measures

Feasibility

We indexed (1) adherence (activity scores, i.e. accumulated number of EMAs and EMIs started and fully completed, with 70 EMAs and EMIs as the maximum number of filled-in surveys, and the time spent actively with the app [objective measures]) and (2) self-reported functionality, aesthetics, and information content, indexed by the user version of the Mobile Application Rating Scale (Stoyanov et al., 2016), indexing key aspects of user experience with the app.

Efficacy

To assess the effects of Imager on mental health, we assessed depressive symptoms, anxiety, and perceived stress using the German translations of the Beck Depression Inventory II (BDI-II) (includes 21 questions, score range = 0–63, consistency $\alpha \geq .84$, and retest reliability $r \geq .75$ after 2 weeks in nonclinical samples) (Kühner et al., 2007), the State–Trait Anxiety Inventory (STAI) (includes 20 questions assessing state, score range = 20–80, consistency $\alpha \geq .96$, and retest reliability $r \geq .50$ after 2 weeks in clinical samples) (Laux et al., 1981), and the Perceived Stress Scale (PSS) (includes 10 questions, score range = 10–40, consistency $\alpha \geq .78$, and retest reliability $r \geq .74$ after 1 week in nonclinical samples) (Klein et al., 2016). We calculated the reliability in our sample as proposed by Koo and Li (2016) with the use of Intraclass Correlation Coefficient (ICC). For all the measures, the reliability was moderate: for BDI-II, ICC = 0.68, $p < .001$; for STAI, ICC = 0.63, $p < .001$; and for PSS, ICC = 0.62, $p < .001$.

Target mechanism

To assess whether the EMI engaged the proposed target mechanism, we indexed changes in reward sensitivity using the German translations of the Reward Responsiveness subscale of the BIS/BAS (includes four questions, score range = 4–16, consistency $\alpha \geq .72$ for the full BAS scale, and retest reliability $r \geq .68$ for 2 weeks in nonclinical samples) (Jorm et al., 1998; Strobel et al., 2001) and the Reward Sensitivity subscale of the Sensitivity to Punishment and Reward Questionnaire (SPSRQ) (includes 24 questions, score range = 0–24, no previous manuscripts on consistency and retest reliability for German version) (Torrubia et al., 2001). In our sample, the reliability for both the Reward Responsiveness scale of BIS/BAS (ICC = 0.63, $p < .001$) and for Reward Sensitivity subscale of SPSRQ (ICC = 0.63, $p < .001$) was moderate.

Procedure

Participant recruitment

Participants were recruited from universities in the greater Zurich area (Switzerland) using announcements on university websites, university department mailing lists, information disseminated by relevant student organizations, and social media. In order to blind participants to the possible group allocation, they were initially informed only that they would use the mobile app (without introducing positive mental imagery before the randomization and baseline assessment). However, participants received detailed information about the experiment, such as the nature of the study, the procedures involved, the expected duration, potential risks and benefits, confidentiality, and incentives. All participants signed an informed consent form.

Screening

Young adults interested in the study were asked to complete a short online form with basic demographic information (age, gender, and education) and reward sensitivity indexed by the items from the BIS/BAS. Individuals who fulfilled the following inclusion criteria were eligible to participate in the study: (1) a student of a higher education institution, (2) 18–29 years old, (3) sufficient knowledge of the German language, (4) a smartphone user, and (5) a score of 5 or more in the (reversed) reward responsiveness subscale of BIS/BAS scales, indicating lowered reward sensitivity. This cutoff was decided after the meeting with stakeholders mirroring the target group. Participants of this meeting had filled in BIS/BAS scales, and subsequently, we calculated the average BIS/BAS score and set up the threshold based on one standard deviation lower from the mean score.

Individuals were excluded from participation if they (1) were attending psychotherapy or receiving support from a qualified psychologist or psychiatrist or (2) had a psychiatric disorder diagnosis (past or current), as indicated by participants in the screening questionnaire. Potential participants were contacted by a researcher and provided with a personal code to use throughout the study.

Baseline meeting

During the baseline meeting, conducted online via a secure video call platform, participants completed questionnaires and received instructions on how to download and use Imager. To ensure unbiased assessment, all participants received the same, standardized instructions regardless of their study condition allocation. Those randomly assigned to the IG were also provided with step-by-step training in generating mental imagery of rewarding activities by trained research assistants, which lasted around 20 min. During training, participants got familiarized with the definition of reward sensitivity based on Corral-Frías et al. (2016) and Kim et al. (2015). Subsequently, they were taught how to perform mental imagery training, starting from abstract scenarios inspired by Blackwell et al. (2015), Holmes et al. (2016), and Renner et al. (2019) and leading to mental images related to their own experiences and autobiographic scenarios.

Follow-up meeting

After 7 days of app use, participants were contacted via video call. To ensure unbiased assessment, all participants received the same standardized instructions regardless of their study condition allocation, and the assessors were blind to this allocation until the debriefing. Participants completed follow-up questionnaires, received a debriefing, and, if they wished, personalized feedback showing their mood fluctuations during the week of app usage. Participants were compensated for their time with either university European Credit Transfer System credit or up to 70 [blinded for review process], depending on their adherence (1 CHF per entry in the app).

Imager app

Part 1: EMA

Our app, Imager, was built on the SEMA3 platform (Koval et al., 2019), an open-source platform developed at the University of Melbourne and widely used in EMA/I studies. Daily mood (i.e. negative and positive affect) and stress levels were indexed using an EMA schedule adapted from Vaessen et al. (2019). Participants received 10 prompts per day to assess how they felt at that moment, and in order to align the procedure and the possibility of self-triggering the surveys with the IG (see Part 2: Mental imagery training section), the CG had an option to trigger more EMAs. The prompts were delivered between 8:30 a.m. and 11:00 p.m., in random time within a 1 h window, and expired after 20 min. A total of 13 items were presented each time (see Figure 1). This is the only part that CG had access to during the study.

Part 2: Mental imagery training

Mental imagery trainings were triggered in two ways: Participants received three training sessions per day after completing the EMA questionnaire (combined with EMA prompts sent within 1 h windows starting at 10:00 a.m., 2:30 p.m., and 7:00 p.m.). In addition, participants could trigger the training combined with EMA whenever they felt that they might benefit from it. Each training session started by asking participants to think about a pleasant event that would occur within the next few hours. If participants had difficulty thinking of such an event, they could use an inspiration module with examples based on behavioral activation tasks from a cognitive behavioral therapy guide (Cully & Teten, 2008). Subsequently, participants were asked to describe their experience based on three pseudo-randomly chosen senses (the set of chosen senses was changed three times per day, as defined by the researchers; see Figure 1).

Part 3: Reminder

A reminder to "keep thinking in positive mental images" was triggered when participants reported a high level of stress (4 points or more on a 7-point scale in response to the item "I feel stressed" in the EMA). This short reminder did not require any specific action from the participants but was only to remind them of the ongoing training.

Part 4: Evening training

An evening training was delivered as an additional retrospection-based intervention within the last (10th) notification on a given day in the evening. Participants were asked to use mental imagery to recall and describe the most pleasant event of the day and rate the vividness and pleasantness of that image.

Analysis

All analyses were performed in R (version 4.0.4), using R Studio (version 1.4.1).

Power analysis

We conducted an a priori sample size estimation with the sjstats package developed for linear mixed models (LMM) (Lüdecke, 2021). Due to the lack of similar studies using EMI to increase reward sensitivity, we decided to base this calculation on the effect sizes reported by other studies employing EMIs to increase mental health. The review of Versluis et al. (2016) suggested an effect size of $d = 0.6$. This effect size was also in line with a recent review summarizing findings from mHealth EMI studies (Marciniak et al., 2020). Therefore, for alpha 0.05, power 80%, and an effect size of $d = 0.6$, the required sample size was 94 participants.

Feasibility, efficacy, and target mechanism analysis

For each participant, we calculated the adherence rate as the number of completed surveys divided by the maximum number of notifications (i.e. 70). For user version of the Mobile Application Rating Scale scores, we summed up the points for each scale and divided them by the maximum possible sum of points for the relevant scale.

The researcher conducting the preprocessing of the data was blinded to participants' group allocation. All participants who completed the study were included in an LMM analysis using the nlme package (Pinheiro et al., 2021), with Group (IG vs. CG) and Time (Baseline vs. Follow-up) as fixed effects. We applied root square or log data transformation when the assumptions for the data were not met. Model selection was based on the Akaike information criterion.

RESULTS

Study sample

Participant enrollment began in October 2020 and finished in April 2021. This 6 month period coincided with the entire second and the beginning of the third wave of the COVID-19 pandemic in [blinded for review]. Of the 1050 volunteers who expressed initial interest in the study, 325 filled in the screening form, of whom 51 did not meet the inclusion criteria, 76 did not provide all required information (e.g. regarding age or education), 85 did not register for the baseline meeting, and 14 withdrew prior to the meeting. A total of 99 individuals completed the baseline assessment and were randomized to the groups. Two participants from the CG resigned due to technical problems with the app (in both cases, the app failed to send notifications, and participants decided to withdraw from the study), one from the CG was excluded from the analysis due to delayed follow-up assessment caused by hospitalization, and one from

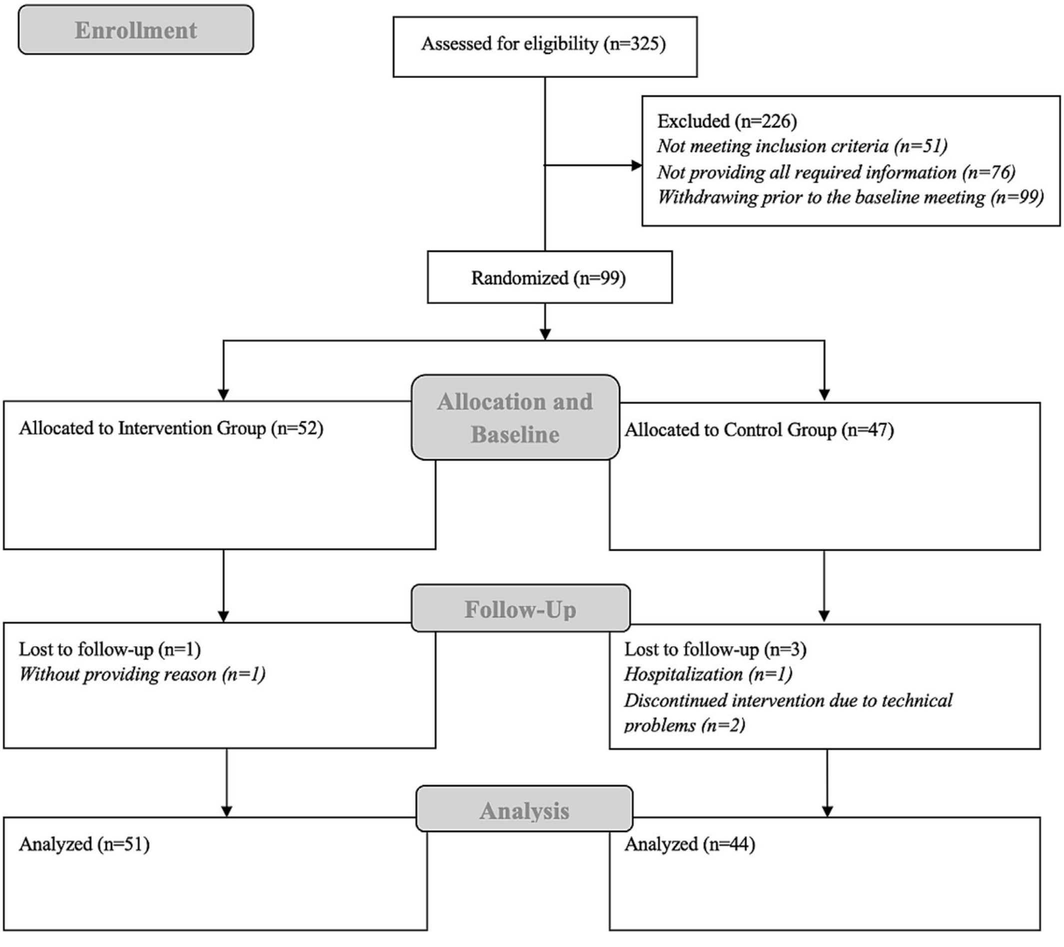

FIGURE 2 CONSORT flow diagram.

the IG did not complete the follow-up assessment. Thus, 95 participants completed the full study procedure (see Figure 2).

Most participants (80%) were female. The mean age was 21.5 years (*SD*: 2.3 years, range: 18–29 years), and there were no significant differences between the groups in terms of age (21.4 years on average in IG vs. 21.7 in CG, $t = 0.66$, $p = .51$), gender (79% females in IG vs. 80% in CG, $t = 0.10$, $p = .92$), education (100% students, of which 94% participants in IG studying Psychology, vs. 86% in CG, $t = 1.41$, $p = .34$), or baseline questionnaire scores (see Tables 1 and A1).

Feasibility

Adherence

As expected during the worldwide pandemic, a considerable subgroup of participants withdrew after the initial screening, before the start of the study procedure. However, the overall

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TABLE 1 Demographic characteristics of the sample and mean questionnaire scores.

Demographics	Full sample	Intervention group	Control group
Age—Mean (*SD*) (years)	21.5 (2.3)	21.4 (1.96)	21.7 (2.6)
Age—Range (years)	18–29	18–26	18–29
% female	80% (76/95)	79% (41/51)	80% (35/44)
% students	100%	100%	100%
Psychology	92% (86/95)	94% (48/51)	86% (38/44)
Other departments	10% (9/95)	6% (3/51)	14% (6/44)
Depressive symptoms in baseline (BDI-II)—Mean (*SD*)	9.58 (7.14)	9.88 (6.29)	9.23 (8.07)
Depressive symptoms in follow-up (BDI-II)—Mean (*SD*)	7.38 (6.06)	6.82 (5.54)	8.02 (6.61)
Anxiety symptoms in baseline (STAI)—Mean (*SD*)	38.52 (9.81)	39.73 (10.02)	37.11 (9.48)
Anxiety symptoms in follow-up (STAI)—Mean (*SD*)	38.35 (8.96)	37.75 (8.99)	39.05 (8.97)
Perceived stress in baseline (PSS)—Mean (*SD*)	28.64 (4.97)	28.67 (5.09)	28.61 (4.88)
Perceived stress in follow-up (PSS)—Mean (*SD*)	27.17 (5.44)	26.37 (5.81)	28.09 (4.88)
Reward responsiveness in baseline (BIS/BAS)—Mean (*SD*)	16.24 (2.17)	16.00 (2.11)	16.52 (2.23)
Reward responsiveness in follow-up (BIS/BAS)—Mean (*SD*)	16.68 (2.28)	16.45 (2.35)	16.96 (2.19)
Sensitivity to reward in baseline (SPSRQ)—Mean (*SD*)	37.58 (3.73)	37.75 (3.45)	37.39 (4.06)
Sensitivity to reward in follow-up (SPSRQ)—Mean (*SD*)	37.72 (3.99)	37.78 (3.53)	37.63 (4.51)

Abbreviations: BDI-II, Beck Depression Inventory II; BIS/BAS, Behavioral Avoidance/Inhibition Scales; PSS, Perceived Stress Scale; SPSRQ, Sensitivity to Punishment and Reward Questionnaire; STAI, State–Trait Anxiety Inventory.

adherence to the Imager was high; participants at least partly completed an average of 69 surveys and fully completed over 65 (including those triggered by the participants themselves) (see Table 2). The CG completed 99% of the surveys, and the mean number of self-triggered EMAs was 19.39. Adherence was lower for the IG at 88%, and on average, IG participants filled in 26.67 EMIs (the planned number of EMIs for the whole study period was 21), out of which 4.97 were self-triggered. The difference between the groups was significant for completed surveys ($t = 2.62$, $p = .01$), meaning that CG completed significantly more surveys than IG, but not for the started surveys ($t = 1.57$, $p = .12$). However, the IG spent significantly more time engaging with Imager than CG ($t = -15.83$, $p < .001$), and this difference is almost double, with, on average, 144.75 min for IG and 75.86 min for CG.

Self-reported app experience

On average, Imager's functionality was rated highly (84%), indicating that participants were satisfied with the app navigation and flow logic. The app aesthetics were also rated highly (78%), indicating that participants found the app visually appealing. Information was rated at 79%, indicating that participants trusted the credibility, relevance, and quality of the information included in Imager. Both groups rated the app experience similarly (see Table 2).

TABLE 2 Adherence and feasibility measures obtained from user version of the Mobile Application Rating Scale.

	Full sample	Intervention group	Control group
Number of surveys started	68.5 (*SD* = 14.40)	66.4 (*SD* = 12.35)	70.9 (*SD* = 15.49)
Number of surveys completed	65.4 (*SD* = 14.00)	61.9 (*SD* = 12.14)	69.4 (*SD* = 15.83)
Percentage of surveys started	98	95	100
Percentage of surveys completed	93	88	99
Time spent with app (min)	113.71	144.75	75.86
Functionality—Percentage (points)	84% (16.9/20)	84% (16.7/20)	85% (17.0/20)
Aesthetics—Percentage (points)	78% (11.7/15)	79% (11.9/12)	76% (11.4/15)
Information—Percentage (points)	79% (15.8/20)	79% (15.7/20)	79% (15.8/20)

Efficacy

Depressive symptoms—BDI-II

Due to the nonnormal distribution of residuals, a log transformation was performed. The hypothesized Group × Time interaction was significant, $\beta = -0.34$, $p = .004$, η_p^2 [90% CI] = 0.09 [0.02, 0.19]. Main effect analysis revealed that participants who used Imager (IG) achieved a greater reduction in depressive symptoms than the CG ($\beta = -0.44$, $p < .001$, η_p^2 [90% CI] = 0.40 [0.22, 0.54] for IG vs. $\beta = -0.11$, $p = .19$, η_p^2 [90% CI] = 0.04 [0.00, 0.18] for CG) (see Tables 1 and 3 and Figure 3a).

Anxiety symptoms—STAI

A data log transformation was performed because of the nonnormal distribution of residuals. The Group × Time interaction was significant, $\beta = -0.10$, $p = .013$, η_p^2 [90% CI] = 0.07 [0.01, 0.16]; however, the main effect analysis revealed that the decrease in anxiety symptoms in IG was not significant ($\beta = -0.05$, $p = .12$, η_p^2 [90% CI] = 0.05 [0.00, 0.18]), and there was a significant increase in anxiety in CG ($\beta = 0.05$, $p = .03$, η_p^2 [90% CI] = 0.11 [0.01, 0.27]) (see Tables 1 and 3 and Figure 3b).

Perceived stress—PSS

Based on the nonnormal distribution of residuals, we performed square root-transformed data transformation. The Group × Time interaction was significant, $\beta = -0.18$, $p = .035$, η_p^2 [90% CI] = 0.05 [0.00, 0.13], showing that participants who used Imager (IG) achieved a greater reduction in perceived stress than the CG ($\beta = -2.6$, $p < .001$, η_p^2 [90% CI] = 0.23 [0.08, 0.38] for IG vs. $\beta = -0.58$, $p = .39$, η_p^2 [90% CI] = 0.02 [0.00, 0.04] for CG) (see Tables 1 and 3 and Figure 3c).

TABLE 3 Efficacy of Imager: Mental health outcomes and target mechanism.

	Value (β)	*SE*	*df*	*t*-value	*p*-value	η_p^2 [90% CI]
Depression (BDI-II)						
Intercept	2.01	0.11	93	18.51	.001	
Time	−0.11	0.08	93	−1.28	.202	0.22 [0.11, 0.34]
Group	0.21	0.15	93	1.41	.169	0.00 [0.00, 0.06]
Time * Group	−0.34	0.11	93	−2.99	.004	0.09 [0.02, 0.19]
Anxiety (STAI)						
Intercept	3.62	0.03	93	105.46	.001	
Time	0.05	0.03	93	1.82	.071	0.00 [0.00, 0.00]
Group	0.06	0.05	93	1.37	.173	0.00 [0.00, 0.03]
Time * Group	−0.10	0.04	93	−2.55	.013	0.07 [0.01, 0.16]
Perceived stress (PSS)						
Intercept	5.33	0.07	93	76.04	.001	
Time	−0.05	0.06	93	−0.78	.435	0.11 [0.03, 0.22]
Group	0.00	0.96	93	0.04	.970	0.00 [0.00, 0.05]
Time * Group	−0.18	0.08	93	−2.14	.035	0.05 [0.00, 0.13]
Reward responsiveness (BAS)						
Intercept	16.52	0.33	93	50.68	.001	
Time	0.43	0.24	93	1.81	.074	0.07 [0.01, 0.17]
Group	−0.52	0.44	93	−1.17	.243	0.02 [0.00, 0.08]
Time * Group	0.02	0.33	93	0.06	.953	0.00 [0.00, 0.00]
Sensitivity to reward (SPSRQ)						
Intercept	37.39	0.56	93	66.28	.001	
Time	0.25	0.33	93	0.76	.450	0.00 [0.00, 0.05]
Group	0.36	0.77	93	0.47	.642	0.00 [0.00, 0.04]
Time * Group	−0.21	0.45	93	−0.47	.641	0.00 [0.00, 0.04]

Abbreviations: BAS, Behavioral Activation Scale (Reward Responsiveness Subscale Score); BDI-II, Beck Depression Inventory II; PSS, Perceived Stress Scale; SPSRQ, Sensitivity to Punishment and Reward Questionnaire (Sensitivity to Reward Subscale Score); STAI, State–Trait Anxiety Inventory (here, state scores are reported).

Target mechanism

Reward sensitivity—BAS reward responsiveness subscale

The model's assumptions were met. The Group × Time interaction was nonsignificant at $\beta = 0.02$, $p = .953$, η_p^2 [90% CI] = 0.00 [0.00, 0.00] (see Tables 1 and 3 and Figure 3d).

Reward sensitivity—SPSRQ sensitivity to reward subscale

The model's assumptions were met. An LMM analysis revealed a nonsignificant Group × Time interaction, $\beta = -0.21$, $p = .641$, η_p^2 [90% CI] = 0.00 [0.00, 0.04] (see Tables 1 and 3 and Figure 3e).

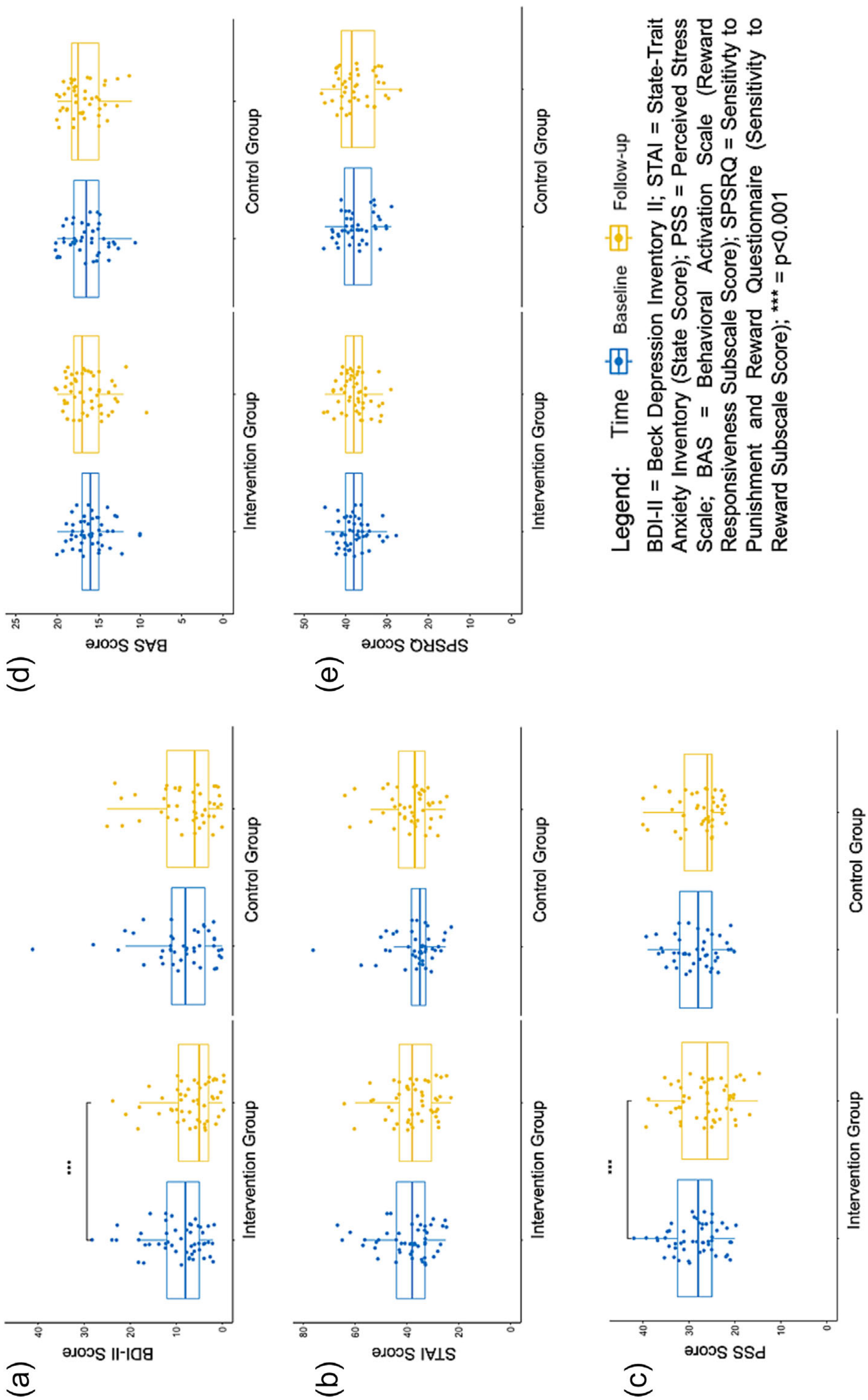

FIGURE 3 Efficacy of Imager: (a and b) Mental health outcomes, (c) perceived stress, and (d and e) target mechanism.

DISCUSSION

Summary of findings

This study was designed to determine the feasibility, efficacy, and target mechanism engagement of Imager, an EMI developed to improve mental health via reward sensitivity to a young healthy sample with lowered scores in a reward sensitivity questionnaire.

The high feasibility of Imager was confirmed by over 93% adherence, including self-triggered surveys. During the 1 week intervention period, only one participant in the IG and three in the CG dropped out. This indicates that participants who decided to participate in the full study procedure were able and willing to integrate the app into their daily routines. A considerable subgroup of participants withdrew after the initial screening, before the start of the study procedure. It is possible that only individuals who expected a potential mental health benefit from the intervention participated in the full procedure.

Imager effectively reduced depressive symptoms and perceived stress within a week. While prior research has shown the efficacy of mental imagery training in treating depression (Holmes et al., 2009; Linke & Wessa, 2017), this is the first study to demonstrate the effectiveness of app-delivered mental imagery training in a young, healthy sample just below the mild depression threshold.

Despite its success in reducing stress and depressive symptoms, Imager did not show clear evidence of engagement with the target mechanism of reward sensitivity via self-report questionnaires. This aligns with ongoing debates about identifying active mechanisms in mental health treatments (Cuijpers et al., 2019). We currently cannot pinpoint the mechanism underlying the reduction of psychological symptoms. To date, most mechanistic evidence has come from neural biomarkers studies (Brehl et al., 2020; Lueken & Hahn, 2016), which was the basis for selecting our target, but which we did not probe in this study. Indeed, previous research suggests that the effects of imagery on behavioral and physiological outcomes may be even greater than its effects on psychological outcomes (Conroy & Hagger, 2018). Additionally, behavioral and neuropsychological measures assessing reward sensitivity correlate with questionnaires such as BIS/BAS quite weakly or not at all (Bress & Hajcak, 2013). Another possibility is that the mechanism targeted by Imager differs from reward sensitivity as captured by the BIS/BAS or the SPSRQ, which measure general tendencies related to reward sensitivity, and could be linked to the number of rewarding activities or the number of mental images created by the participants, for example.

Limitations

Limitations in our study include relying solely on self-reported measures to assess mental health and reward sensitivity due to COVID-19 data collection constraints. Future research should incorporate diverse assessment methods and study designs, such as Sequential Multiple Assignment Randomized Trials (Lei et al., 2012) or Multiphase Optimization Strategy (Collins, 2018), to enhance intervention effects. Due to changes in the procedure and the necessity to align it to the pandemic setting, the study was registered retrospectively in the clinical trials registry. Adherence differences between groups may be attributed to survey expiration times, and real-world app usage may exhibit lower adherence without financial incentives.

Additionally, the study's homogenous sample of young, healthy, primarily female psychology students limits generalizability of the findings. The COVID-19 pandemic may have influenced reported rewarding activities, affecting the app's effectiveness. Lack of comparison IGs warrants further exploration of underlying mechanisms driving cognitive and affective changes in mental health outcomes. Long-term observation and stressor exposure assessment are needed to confirm Imager's efficacy, particularly given the short intervention period (Chmitorz et al., 2018). Moreover, while IG questionnaire scores decreased by approximately 3 points for BDI-II and 2.3 points for PSS, practical implications of these mental health symptom changes in real-life scenarios remain uncertain.

Strengths

Despite limitations, this study uniquely assessed the impact of mental imagery delivered through an EMI mobile app on reward sensitivity. The study's controlled design and choice of control condition mitigated potential bias from app expectations. Promising effects on mental health, particularly depressive symptoms, and high feasibility suggest increased research interest and potential clinical use for EMIs in addressing therapeutic challenges related to accessibility and scalability (Mansell, 2008).

Conclusions

Imager is a feasible and effective app. Participants found it easy to integrate the use of Imager into their daily routines, and it reduced depressive symptoms and perceived stress in healthy young adults. These findings align with existing literature confirming the positive effects of mental imagery on mental well-being. However, we were not able to detect target mechanism engagement based on self-reported reward sensitivity. Because the mechanisms underlying such effects remain unknown, prospective studies should focus on addressing this issue, using additional measures as well as clinical and more heterogeneous samples.

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CONFLICT OF INTEREST STATEMENT

R. K. received advisory honoraria from JoyVentures, Herzlia, Israel. Other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The self-report data used to support the findings of this study are restricted by the Ethics Committee of the Faculty of Arts and Social Sciences of the University of Zurich in order to protect participants' privacy. Data are available from the corresponding author under reasonable request.

ETHICS STATEMENT

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by The Ethics Committee of the Faculty of Arts and Social Sciences of the University of Zurich (#20.6.11). Informed consent was obtained from all individual participants included in the study. ClinicalTrials.gov identifier: NCT05623826.

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APPENDIX A

TABLE A1 Demographic characteristics of the sample, mean questionnaire scores, and statistical differences between the groups in baseline.

Demographics	Full sample	Intervention group (IG)	Control group (CG)	Difference between the IG and CG (*t*-value, *p*-value)
Age—Mean (*SD*) (years)	21.5 (2.3)	21.4 (1.96)	21.7 (2.6)	0.66, 0.51
Age—Range (years)	18–29	18–26	18–29	—
% female	80% (76/95)	79% (41/51)	80% (35/44)	0.10, 0.92
% students	100%	100%	100%	—
Psychology	92% (86/95)	94% (48/51)	86% (38/44)	0.95, 0.34
Other departments	10% (9/95)	6% (3/51)	14% (6/44)	
Depressive symptoms in baseline (BDI-II)—Mean (*SD*)	9.58 (7.14)	9.88 (6.29)	9.23 (8.07)	−0.50, 0.62
Depressive symptoms in follow-up (BDI-II)—Mean (*SD*)	7.38 (6.06)	6.82 (5.54)	8.02 (6.61)	[a]
Anxiety symptoms in baseline (STAI)—Mean (*SD*)	38.52 (9.81)	39.73 (10.02)	37.11 (9.48)	−1.51, 0.13
Anxiety symptoms in follow-up (STAI)—Mean (*SD*)	38.35 (8.96)	37.75 (8.99)	39.05 (8.97)	[a]
Perceived stress in baseline (*PSS*)—Mean (*SD*)	28.64 (4.97)	28.67 (5.09)	28.61 (4.88)	0.24, 0.81
Perceived stress in follow-up (*PSS*)—Mean (*SD*)	27.17 (5.44)	26.37 (5.81)	28.09 (4.88)	[a]
Reward responsiveness in baseline (BIS/BAS)—Mean (*SD*)	16.24 (2.17)	16.00 (2.11)	16.52 (2.23)	−1.27, 0.21
Reward responsiveness in follow-up (BIS/BAS)—Mean (*SD*)	16.68 (2.28)	16.45 (2.35)	16.96 (2.19)	[a]

TABLE A1 (Continued)

Demographics	Full sample	Intervention group (IG)	Control group (CG)	Difference between the IG and CG (t-value, p-value)
Sensitivity to reward in baseline (SPSRQ)—Mean (*SD*)	37.58 (3.73)	37.75 (3.45)	37.39 (4.06)	−0.47, 0.64
Sensitivity to reward in follow-up (SPSRQ)—Mean (*SD*)	37.72 (3.99)	37.78 (3.53)	37.63 (4.51)	[a]

Abbreviations: BDI-II, Beck Depression Inventory II; BIS/BAS, Behavioral Avoidance/Inhibition Scales; PSS, Perceived Stress Scale; SPSRQ, Sensitivity to Punishment and Reward Questionnaire; STAI, State–Trait Anxiety Inventory.

[a]See Table 3 in the main text.

APPENDIX B: INTRACLASS CORRELATION COEFFICIENTS (ICC) FOR LINEAR MIXED MODELS

Depressive symptoms—Beck Depression Inventory II.

ICC(1) = 0.67, $p < .001$, ICC(2) = 0.80.

Anxiety symptoms—State–Trait Anxiety Inventory.

ICC(1) = 0.63, $p < .001$, ICC(2) = 0.77.

Perceived stress—Perceived Stress Scale.

ICC(1) = 0.61, $p < .001$, ICC(2) = 0.76.

Reward sensitivity—Behavioral Activation Scale, Reward Responsiveness Subscale.

ICC(1) = 0.73, $p < .001$, ICC(2) = 0.85.

Reward sensitivity—Sensitivity to Punishment and Reward Questionnaire, Sensitivity to Reward Subscale.

ICC(1) = 0.84, $p < .001$, ICC(2) = 0.91.