A Scoping Review on the Use of Technology in Cognitive Bias Modification for Interpretation Biases

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Abstract

Objective: Cognitive bias modification for interpretation (CBM-I) describes a method of modifying the negative interpretation biases that underly many psychopathological disorders. While the implementation of technology in CBM-I enables advancements in delivery and measurement, no review on CBM-I has so far considered the peculiar characteristics and benefits of different kinds of technology. This scoping review aims to map recent findings on the use of technology in CBM-I, targeted populations, intervention designs, and measured outcomes.

Methods: Searching of the databases Scopus, Web of Science, PsycINFO, and additional hand-searching and snowballing resulted in a total of 12 studies. Data extracted covered participant characteristics, study characteristics and outcomes, and technology and intervention designs.

Results: Most interventions targeted anxiety samples and measured clinical effects or intervention feasibility. Feasibility was mostly high while clinical effectiveness yielded mixed results. Technology was predominantly applied in the delivery, most often through smartphone apps or multimedia online programmes that were intended as stand-alone treatments. Highlighted benefits of the implementation of technology were personalization, improved effectiveness through activated schemata, enhanced user experience, and the possibility to adjust for cognitive deficits.

Conclusion: While the implementation of technology seems highly feasible and could contribute to making CBM-I more enjoyable and accessible, further research is needed to identify the conditions under which interventions obtain reliable clinical effects. Moreover, the utilization of technology in the measurement process could enable more valid measurement tools than the ones currently being applied and offer possibilities for measuring actual intervention effects in daily life.

A Scoping Review on the Use of Technology in Cognitive Bias Modification for Interpretation

Social encounters often leave a lot of room for interpretation. Did your neighbour not greet you because she did not see you or because she is angry at you? When individuals tend to repeatedly answer questions like these in a negative manner, their thinking might be influenced by a negative interpretation bias. Interpretation biases are a type of cognitive bias that often contribute to the development and maintenance of psychopathological disorders, such as anxiety or depression (Beard, 2011; Kennerley et al., 2016; MacLeod & Mathews, 2012). Cognitive bias modification for interpretation (CBM-I) is a form of treatment that has shown some promise although results are mixed and effect sizes are often only moderate (Chen et al., 2022; Jones & Sharpe, 2017). Technological progress, however, facilitates improvement in the design and delivery of CBM-I interventions, while making CBM-I more flexible, accessible, engaging, and less time-consuming (Brettschneider et al., 2015; Cougle et al., 2017; Zhang et al., 2019). The field of interventions has, from simple computer applications, expanded to mobile apps, virtual reality (VR), and gamified interventions. Previous reviews on the effectiveness of CBM-I interventions have either not considered technological aspects or only examined them on a surface level, without paying closer attention to their characteristics and benefits (Kuckertz & Amir, 2017; Martinelli et al., 2022; Zhang et al., 2018a; Zhang et al., 2018b; Zhang et al., 2019). In order to create an overview of the state of the art of the field, the aim of this paper is to review, summarize, and synthesize recent findings on the use of different kinds of technology in CBM-I, targeted populations, and evidence of its effectiveness.

Cognitive bias modification for interpretation

Interpretation biases, which are a subtype of cognitive biases, refer to the tendency to interpret ambiguous situations or stimuli in a particular way (Beard, 2011; Kennerley et al., 2016; MacLeod & Mathews, 2012). While such biases are a normal part of information processing, they can become chronic or exaggerated in a negative direction and lead to dysfunctional thinking patterns that contribute to the development and maintenance of psychopathological disorders (Beck & Haigh, 2014; Fisher, 2012; Kennerley et al., 2016; Woud, 2022). Negative or dysfunctional interpretation biases have been found to play a role in the maintenance of depression and anxiety disorders (Everaert et al., 2017; Hirsch et al., 2016) and contribute to variations in anxiety vulnerability (MacLeod & Mathews, 2012). Individuals with social anxiety disorder, for example, tend to interpret ambiguous information and their own behaviour in social situations in a more negative manner (Hirsch et al., 2016). Another example is the negative and catastrophic interpretation of harmless bodily sensations in individuals with panic disorder (Hirsch et al., 2016).

While conventional approaches for treating interpretation biases, such as cognitive behavioural therapy, aim at teaching skills to become aware of and control one's interpretation of stimuli, cognitive bias modification for interpretation (CBM-I) which, along with attention bias modification (ABM), is one of the two most common forms of cognitive bias modification (CBM) (Jones & Sharpe, 2017) assumes that cognitive biases are more automatic and implicit and cannot consciously be controlled (Beard, 2011). In order to increase the tendency to interpret ambiguous situations more positively, individuals are presented with cognitive training tasks that request them to repeatedly (e.g., 100 situations in 10 minutes) interpret neutral information in a benign way (Beard et al., 2021; Kuckertz & Amir, 2017). In the ambiguous scenarios task, for example, participants read about short scenarios that are neutral until they, in the end, have to choose either a positive or negative resolution (Kuckertz & Amir, 2017). To promote positive interpretations, they are provided with affirmative feedback (i.e., "correct") for choosing benign resolutions and negative feedback (i.e., "incorrect") for choosing negative ones.

To synthesize the large number of studies that have been conducted on the effectiveness of CBM-I, a few meta-analyses with mixed results have been published. In a meta-analysis that, besides other types of CBM included 23 interventions based on CBM-I, Cristea et al. (2015) only found small, and for clinical samples even non-significant, effects of CBM-I on anxiety and depression outcomes. Moreover, they rated the quality of most studies as deficient and attributed the found effects to probable publication bias. In contrast, in a more recent meta-analysis of twelve meta-analyses, Jones and Sharpe (2017) conclude that CBM-I successfully modifies targeted biases in adults and has positive effects on anxiety and stress vulnerability. Based on their findings, they advise the future use of CBM-I in the treatment of anxiety (Jones & Sharpe, 2017). However, the reduction of anxiety symptoms through CBM-I was only shown in the short-term (Jones & Sharpe, 2017). The most recent and largest meta-analysis of the effects of CBM-I considered 70 samples with a variety of methodological parameters (Martinelli et al., 2022). Overall, Martinelli et al. (2022) conclude that interpretation biases can successfully be modified by CBM-I in both clinical and non-clinical samples and that its application among different diagnostic categories is therefore justified. However, notably, the review focused on effects on biases instead of symptom reduction but concluded that, while CBM-I may not have a direct effect on symptoms, it may prevent symptom outburst when faced with a stressor (Hallion & Ruscio, 2011, as in Martinelli et al., 2022).

Technology in CBM-I

The integration of technological advances into CBM-I offers a wide field of new opportunities. The shift from delivering CBM-I on a computer in a lab to providing completely digitalized interventions online without the need for assistance lowers the barrier for clients to make use of CBM-I (Martinelli et al., 2022). Since in technological stand-alone treatments like these no therapist and no laboratory are needed, they additionally eliminate geographical barriers and make CBM-I less time-consuming and more flexible and accessible for a larger number of clients (Brettschneider et al., 2015; Cougle et al., 2017). Contrary to technological stand-alone treatments, blended care interventions do not aim to replace face-to-face treatments and instead combine the benefits of both approaches in one integrated treatment that constitutes both technological elements and face-to-face contact (Erbe et al., 2017). Blended care could help clients master the transition from psychiatric care to outpatient care and lower the risk of relapse (Beard et al., 2021).

Furthermore, the individual characteristics of different kinds of technology open completely new possibilities. Adding gamification or multimedia elements could make the highly repetitive and monotonous tasks in CBM-I more engaging and increase clients' motivation (Boendermaker et al., 2015). Virtual reality could, moreover, let users experience ambiguous scenarios more realistically and in a way that elicits stronger emotional responses than when just reading about them. This benefit of immersion is already successfully being employed in exposure therapy and the treatment of psychosis and could, in CBM-I, possibly serve to achieve stronger effects on interpretation bias that might be better translatable to real life (Riches et al., 2021; Wechsler et al., 2019). Despite the first CBM-I interventions having been tested in the early 2000s (Menne-Lothmann et al., 2014), the research field of technology-based CBM-I is still in its infancy, and in the recent years, several new developments, such as smartphone apps, virtual reality, and gamification have shaped the field.

To date, only three reviews have been conducted on technology-based CBM-I interventions. One of them focused on interventions delivered via smartphone-app, another one on gamified interventions, and the third one on web-based interventions (Zhang et al., 2018a; Zhang et al., 2018b; Zhang et al., 2019). These reviews, however, did not consequently differentiate between CBM-I and ABM which might distort their conclusions, as CBM-I has before been shown to reduce symptoms more effectively than ABM (Cristea et al., 2015; Jones & Sharpe, 2017). Other reviews, such as the one by Martinelli et al. (2022) included online interventions without considering their peculiar characteristics and differences in comparison to other forms of delivery. Kuckertz and Amir (2017) identified that previous reviews have often examined CBM-I in a broader context of CBM in general which disregarded the heterogeneity among studies, and therefore advised future researchers to ask more focused questions and differentiate between different populations and delivery settings, instead of assessing if CBM-I is effective under all conditions. This may partially explain the mixed results in earlier studies and meta-analyses and highlights the need for a more detailed review that orders information according to these differences and considers different third variables. So far, no review has focused on the state of the art of technology in CBM-I, considering different kinds of technology, different populations, and different ways of delivery. Lastly, innovative developments, such as a mobile virtual reality CBM-I training (Otkhmezuri et al., 2019), that have enriched the field in recent years, have not yet been considered in any of the reviews.

The current study

The current study aims at closing the above-identified research gap by reviewing, summarizing, and mapping recent findings on technology-based CBM-I interventions. Prior studies and meta-analyses were indecisive about the effectiveness of CBM-I interventions. As they often did not differentiate between ABM & CBM-I, consider the benefits of technology and how these might combat limitations of traditional CBM-I, and emphasize the characteristics of different kinds of delivery or measurement, to this point, no clear conclusions about the scope, quality, and effectiveness of technology-based CBM-I interventions can be drawn. The aim of this review is to create an overview of recent findings on the use of different kinds of technology in CBM-I, targeted populations, kinds of studies conducted and measured outcomes. A search of the international prospective register of systematic reviews (PROSPERO) has affirmed that there is no overlap with other systematic reviews currently worked on. The following five research questions were formulated based on the PICO-framework, a tool for articulating focused questions for clinical research considering the key elements population, intervention, potentially control, and outcomes (Schardt et al., 2007).

1. What participant groups with which psychological conditions were targeted by technology-based CBM-I interventions?

2. What data was collected and what outcomes were reported in terms of feasibility and effectiveness?
3. What type of technology was used and what was its role within the intervention (measurement or delivery)?
4. What were the characteristics of the intervention designs and the dynamics of human-technology interplay (technology as stand-alone treatment/measure or blended care)?
5. What benefits did the intervention achieve through the implementation of technology?

Methods

The present literature is a scoping review. Scoping reviews aim at mapping literature and determining the range of existing evidence (Peters et al., 2015). As described above, research on technology in CBM-I that goes beyond conventional in-lab computers is still in its infancy and reviews so far have not thoroughly looked at the variety of options and potential benefits yet. Thus, a scoping review deemed appropriate, as, in contrast to systematic reviews, scoping reviews consider literature with heterogenous study designs and are especially useful for emerging areas of study that have not been reviewed comprehensively yet and therefore yield a limited familiarity (Arksey & O'Malley, 2005; Peters et al., 2015; Tricco et al., 2018). Potential purposes for scoping reviews are determining types of existing evidence, identifying key characteristics related to a specific concept, or laying the foundation for eventual systematic reviews which match the aims of the present review (Munn et al., 2018). The preparation and execution of this scoping review were conducted in accordance with the methodological guidelines by Peters et al. (2015) while the reporting followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) and the PRISMA extension for scoping reviews (PRISMA-ScR) (Page et al., 2021; Tricco et al., 2018). This scoping review is based on a protocol that was drafted using the preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement (Moher et al., 2016). Although the protocol is not made publicly available, a digital copy can be requested from the author.

Eligibility criteria

The following inclusion and exclusion criteria were applied:

Table 1

Eligibility criteria

Inclusion criteria	Exclusion criteria
Articles needed to be written either in English or in German.	Studies did not report scientific research
Articles needed to report original research (no literature reviews).	Studies did not differentiate between CBM-I and other kinds of cognitive bias modification.
The publication date of the articles needed to be 2018 or later in order to limit the scope while including the most recent findings and excluding outdated sources.	The role of technology did not exceed the one of in-lab computers of traditional CBM-I interventions
Studies needed to investigate a CBM-I intervention that was either delivered through or measured by some form of technology.	
Studies needed to include an outcome measure of interpretation biases, psychopathological symptoms, or the usability and feasibility of the intervention.	

Search Strategy

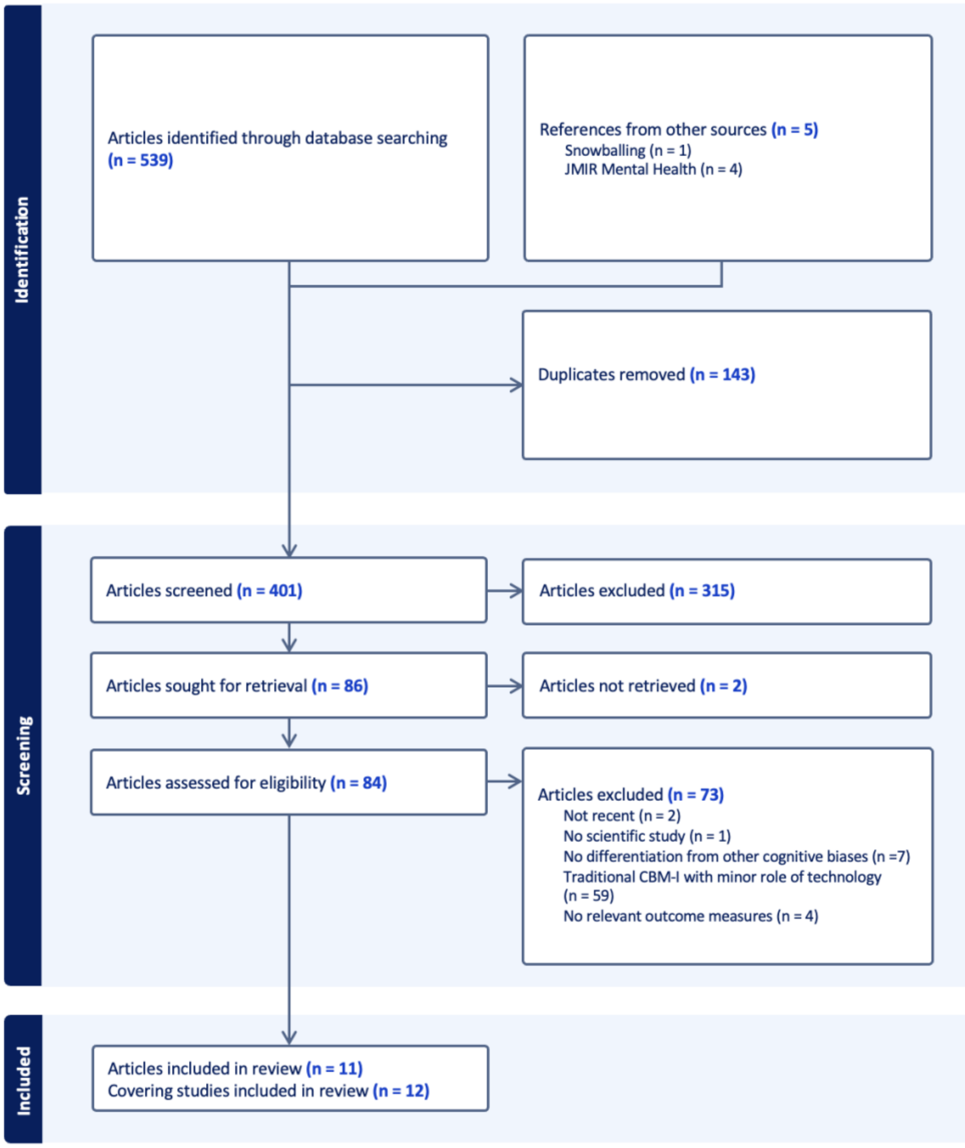
To identify relevant literature, the electronic databases Scopus, Web of Science, and PsycINFO were searched for publications between 2018 and 2023. Due to its emphasis on technical research, the database IEEE has been taken into consideration but was eliminated after a preliminary search revealed a lack of literature on the topic of CBM. PsycINFO was selected because of its narrower focus on psychology and mental health research. Because of the interdisciplinary nature of this review, Web of Science and Scopus were selected as additional resources. Due to their considerable number of peer-reviewed articles across a broad range of research fields, they were expected to yield valuable results and ensure the completeness of contents. The search of the databases was narrowed by filtering the results to English and German articles published in the period from 2018 to 2023. During data collection, the search was conducted in an iterative process by one author. The most recent search was executed on 26.02.2023. The search of databases was supplemented through hand-searching the journal for peer-reviewed articles JMIR Mental Health, as its focus on internet interventions, technologies, and digital innovations for mental health and behaviour change is congruent with the primary areas of interest of this review. Lastly, the selected set of articles was expanded by scanning reference lists for further articles through backward snowballing (as suggested by Wohlin, 2014). The databases were searched with the following search string, adapted to the respective database: TITLE-ABS-KEY ((("cognitive bias" AND interpretation) OR (interpretation NEAR/3 bias)) AND (modif* OR treat* OR chang* OR intervention OR train*) AND (online OR web-based OR web OR gamified OR game OR "virtual reality" OR app* OR computer OR technolog* OR bot OR "artificial intelligence" OR biofeedback OR "augmented reality" OR *phone)) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023))

Selection of sources of evidence

After removing duplicates, all articles were first screened based on their title and abstract. The remaining articles were read completely, and their eligibility was examined based on inclusion and exclusion criteria. To prevent errors and make the process of study selection more efficient and transparent, the open-source software implementation Covidence (www.covidence.org) was used for screening and full-text reviewing. Figure 1 depicts a flowchart that illustrates the process of study selection in accordance with the PRISMA guidelines (Tricco et al., 2018).

Figure 1

PRISMA flow diagram of the selection of sources of evidence



Data extraction and synthesis of results

All selected articles were fully read and analysed by one researcher. Data extraction was conducted on the web-based collaboration software platform Covidence (www.covidence.org). With reference to the established research questions, an extraction protocol was developed and applied. Data items that were extracted covered participant characteristics, study characteristics and outcomes, and technology and intervention design. The evidence was presented in tables by data item. Information of interest that was not provided in the articles was labelled as *not specified*.

Participant characteristics

The first area of interest was the kind of populations that are targeted by technology-based CBM-I interventions. We extracted information about gender and age of participants and examined if the samples were clinical or non-clinical. In clinical samples, we described the classifications, symptoms, or bias tendencies, as declared in the articles.

Study characteristics and outcomes

Regarding the study characteristics, we extracted the study design, the sample size and determined what kind of data was collected. Moreover, we extracted the outcomes of the CBM-I intervention on both effectiveness and feasibility and participant impressions.

Technology and intervention design

For technology and intervention design we extracted the type of technology used (smartphone app, mobile-based VR, etc.) and determined its role in the intervention (delivery or measurement). We, moreover, extracted the benefit of the application of technology, the described intervention design, and the dynamics of the human-technology interplay (stand-alone treatment or blended care).

Results

Selection and characteristics of sources of evidence

For this scoping review, a total of 11 articles covering 12 studies were reviewed. The selection process is depicted in Figure 1.

Research question 1: Participant characteristics

Among the studied articles, a variety of samples were focused on. Most studies focused on clinical samples (n=8) versus completely non-clinical samples (n=1). Among the clinical samples, the most common psychological conditions were anxiety disorders or anxiety symptoms (n=6), anxiety or depressive symptoms (n=1), or a combination of anxiety symptoms and heightened negative interpretation bias (n=1). Other populations assessed were parents with anxiety symptoms and negative interpretation bias whose children (ages eight to sixteen) were on waitlists for child anxiety clinics (n=1) and an inclusive sample of pupils of whom a quarter had neurodevelopmental disorders (such as ADHD or dyslexia) or special educational needs in learning, speech, or socio-emotional development while the other three quarters were non-clinical (n=1). Most samples were predominantly female (n=8). While most samples comprised participants with an average age in their early twenties (n=6), there were three samples with older participants and one sample consisting of younger pupils. Two studies provided only limited sample characteristics. See Table 2 for an overview of the participant characteristics.

Table 2
Participant characteristics

	References	Participant group: Psychological condition	Gender	Age in years, Mean (SD)
1	Beard et al. (2021)	Moderately severe anxiety or depressive symptoms	64% female	35 (15.4)
2	Beard et al. (2022)	Parents of children with anxiety: Anxiety symptoms and negative interpretation bias	85.71% female	44.4 (5.0)
3	Boukhechba et al. (2018)	Social anxiety	Not specified	Not specified
4	Burley et al. (2020)	Not specified	Not specified	Not specified
5	Nieto & Vazquez (2021)	Non-clinical	85% female	21.6 (3.5)
6	Daniel et al. (2020)	Social anxiety	73.6% female	20.4 (3.0)
7	Daniel et al. (2021)	Social anxiety	73.5% female	20.5 (3.0)
8	Otkhmezuri et al. (2019)	Trait and state anxiety	54.8% female	21.6 (3.0)
9	Salemink et al. (2022)	Heightened trait anxiety	78,5% female	21.9 (3.3)
10a	Schmidt & Vereenooghe (2021)	Inclusive school pupils: 1/4 neurodevelopmental disorders or special educational needs	49.3% female	12.2 (1.5)
10 b	Schmidt & Vereenooghe (2021)	“	56.5% female	Not specified
11	Weisberg et al. (2022)	Patients in a primary care medicine practice: GAD, SAD, or panic disorder	72.5% female	42 (14.91)

Note: GAD = generalized anxiety disorder, SAD = social anxiety disorder

Research question 2: collected data and outcomes

All study characteristics and outcomes are summarized in Table 3. Most of the articles reported CBM-I intervention tests (*n*=11), while one study explored a novel way of measuring the outcomes of CBM-I interventions (*n*=1). Among the studies examining interventions, two stood out through their innovative methodology: One of them applied an ecological momentary assessment (EMA) approach that focused specifically on state measures rather than solely relying on trait measures and examined whether CBM-I influences emotions in daily life. The second one used passively collected GPS data to examine behavioural intervention effects in daily life by measuring whether the CBM-I intervention affected the time spent at home, time spent at others' houses, and the number of different locations visited. Of the studies that aimed at testing interventions, four focused on measures of feasibility and participant impressions while the others predominantly collected data to measure the outcomes of the CBM-I training, such as negative interpretations or anxiety symptoms (*n*=4). Three studies measured both. The study that aimed at exploring a new method of measuring CBM-I effects collected EMA-self-report affect ratings, as well as heart rate and accelerometer data.

Five of the eight studies examining anxiety symptoms found clinically relevant intervention effects, although in one study, these effects were only found in the short-term and not in a 1-month follow-up. Noticeably, studies that did find effects on anxiety without restrictions were a pilot feasibility open trial, a proof-of-concept semi-experimental study and a pilot randomized controlled trial (RCT). Of the two RCTs, one did not find any significant effects ($F[1,116]=1.05$, $p=.31$), while one found effects that were, however, not unique to the experimental group ($\beta=-.79$, $p<.001$). Of the two studies measuring depression outcomes, one was an RCT and one an open trial with a pre-post design. Only the open trial found a clinically relevant intervention effect, although, again, the effect could only be measured from baseline to post-intervention, while depression symptoms significantly worsened from baseline to the 1-month follow up. In the RCT, no significant effects on depressive symptoms were observed ($t[117] = -0.88$, $p = .07$).

Five studies reported significant changes in interpretation bias, one of them in hostile attributions, more specifically. These five studies included one RCT ($\beta=-.57$, $p<.01$), one semi-experimental between-subjects design ($t[41] = 4.7$, $p <.001$), two pilot RCTs, and one open trial. In two studies (one RCT and one 2x2 between-subjects design), the results were unclear, as different measurement tools yielded different results. All studies that set benchmarks for feasibility (*n*=3) and adherence (*n*=2) met these benchmarks, while in studies with a-priori benchmarks for acceptability (*n*=3), most benchmarks were met with the exception of one study that only met four of the five sub-benchmarks. In studies in which no benchmarks were referred to, adherence, likeability measures, and engagement were still considered high. The study that explored a new measurement method resulted in finding support for the idea that the correlation between accelerometer and heart rate could be used to detect high stress levels and thereby predict changes in negative affect. Lastly, the study working with passively collected GPS data, although not finding clinically relevant intervention effects, resulted in presenting a robust framework to assess behavioural intervention effects and monitor clients' progress in daily life.

Research question 3: type and role of technology

Table 4 presents an overview of technology and intervention designs. In most cases, technology took the role of delivering an intervention (*n*=9) while in the remaining studies, technology was utilized to measure the effects of an intervention (*n*=3). The type of technology ranged from smartphone apps (*n*=3) to a 3D VR game (*n*=1), a computer game (*n*=1), mobile sensing (*n*=2), EMA (*n*=1), and multimedia online training (*n*=4). The multimedia online training varied and comprised different components, such as instructional and informational videos, audio-voiceovers and narrations, personalization processes, a way of communicating with the primary care provider, and training sessions with scenarios presented as animated videos or cartoon pictures, or in narrated or written-out form. Of the studies employing mobile sensing (*n*=2), one did so in the form of passively collecting GPS data via smartphones, while the other one focused on detecting stress levels by correlating heart rate and accelerometer data collected through smartphones and smartwatches and comparing it to EMA self-report data.

Research question 4: intervention design and human-technology interplay

The intervention designs varied in their numbers and frequency of CBM-I training sessions. The total number of sessions varied from 1 to approximately 12. Regarding the training frequency, most interventions required their participants to complete sessions daily (*n*=4; one of them followed by a phase of three sessions a week) for either six days (*n*=3) or during acute treatment (*n*=1). Of the nine studies in which technology took the role of delivery, most technological interventions were intended as stand-alone treatment (*n*=7). Two of the studies presented a blended care intervention. One of them was meant to serve as an adjunct to acute psychiatric treatment and to facilitate the transition phase from acute treatment to outpatient care. The second one involved an online intervention supervised by a coach who introduced the patients to the process, assisted during weekly check-ins, monitored progress and safety, and served as a link between patient and primary care. Although the intent of the human-technology interplay was less pronounced in the studies, in which technology took the role of a measurement tool, two studies introduced the measurement method more as a complementary tool in outcome measuring, while one study introduced their method as a substitute for self-report measurements.

Research question 5: benefits of the implementation of technology

For the delivery of interventions, researchers indicated a variety of benefits of the respective technologies used, including personalization of the training content, improved activation of memory schemas, improved and more enjoyable user experience, and the possibility to adjust for cognitive deficits. Regarding the measurement, established benefits were the elimination of self-report bias, the obtainment of state measures, and the unobtrusive measurement of actual behaviour in the moment instead of perceived behaviour measures after the intervention. Moreover, it is assumed that the use of technology in measuring intervention effects could minimize participant and clinic burden.

Table 3

Study characteristics and outcomes

	References	Sample size	Aim of the study	Study design	Collected data	Effectiveness outcomes	Feasibility outcomes & participant impressions
1	Beard et al. (2021)	14	Develop and open trial test the smartphone-delivered intervention HabitWorks	Open trial (within-subjects pre-post)	Depression symptoms and anxiety symptoms; adherence, feasibility, acceptability	Baseline to posttreatment: improvement of depression symptoms ($t(9) = 3.2$; $p = .011$) and anxiety symptoms ($t(9) = 4.14$; $p =.003$) baseline to 1-month-follow-up: depression symptoms significantly worsened: $t(9) = –3.68$, $p = .005$; no significant change in anxiety symptoms: $t(9) = –1.55$, $p = .155$	Adherence: (benchmark = 75%) good adherence during acute treatment: 78% completed at least five daily sessions ($M = 6.75$, $SD = 1.29$, range = 4–8), high dropout in 3-month follow-up feasibility (benchmark = 50%): 71% provided consent all a priori benchmarks (=5) for acceptability met: helpfulness (M=5.3, SD=1.9), relevance (M=5.6, SD=0.8), user friendliness (M=5.9, SD=2.1), satisfaction (M=5.8, SD=2.0), and recommendation (M=5.3, SD=1.9)
2	Beard et al. (2022)	14	Test feasibility and acceptability of HabitWorks in parents of children with anxiety	Pilot feasibility open trial (within-subjects pre-post)	Feasibility, adherence acceptability	Significant decrease in anxiety severity from pre-treatment to post-treatment: $F(1.28, 16.638) = 5.8$, p=.021	Feasibility (benchmark = 50%): 87.5% provided consent adherence (benchmark = 50% complete 3 exercises per week): met each week (85.7% in week 1; 78.6% in week 4) 4/5 a priori benchmarks (=5) for acceptability met:

	References	Sample size	Aim of the study	Study design	Collected data	Effectiveness outcomes	Feasibility outcomes & participant impressions
							helpfulness (*M*=5.4, *SD*=1.5), relevance (*M*=4.7, *SD*=1.9), user friendliness (*M*=6.21, *SD*=1.42), satisfaction (*M*=5.5, *SD*=1.65), and recommendation (*M*=5.63, *SD*=1.9)
3	Boukhechba et al. (2018)	20	Explore method to examine physiological changes due to CBM-I in daily life	Open trial (within-subjects pre-post)	EMA (state) self-report affect ratings, heart rate, accelerometer data	Decrease of interpretation bias and negative affect for 10/14 participants	The patterns of change were the same for the correlations between heart rate and accelerometer data, negative affect, and interpretation bias. This provides support for the idea that the correlation between accelerometer and heart rate data can predict changes in negative affect following CBM-I. Therefore, passively collected heart rate and accelerometer data could replace self-report affect measures to track changes due to CBM training
4	Burley et al. (2020)	5	Implement and test new features to the MindTrails program (prototype test)	Pilot prototype test	User's opinions about the prototype	Not applicable	On 5-point Likert scale liking the app (M=4.6) engagement (4.4 of 5)
5	Nieto & Vazquez (2021)	121	Examine effectiveness of CBM-I of the "Relearning	RCT	Cognitive biases; anxiety, depression, and stress	No significant interaction effect of group and time on anxiety (F[1,116]=1.05, p=.31) or stress (F[1,116]=0.65, p=.42);	

	References	Sample size	Aim of the study	Study design	Collected data	Effectiveness outcomes	Feasibility outcomes & participant impressions
			how to think" program			No significant direct effect on depressive symptoms (t[117] = -0.88, *p* = .07) Significant interaction effect of group and time on self-reported interpretation bias (*F*[1,117]=14.24, *p*<.001) but not when measured experimentally (*F*[1,117]=3.73, *p*=.056)	
6	Daniel et al. (2020)	106	Examine effectiveness of online CBM-I intervention through trait and state measures	RCT	Trait: negative interpretation bias trait and state: social anxiety symptoms, fear of negative evaluation	Significant decline on trait negative interpretation bias in the experimental group (*β*=-.57, *p<.01)*, significant declines on trait (*β*=-.79, *p<.001)* and state (*β*=-.16, *p<.05)* social anxiety in both groups (not unique to CBM-I)	Not applicable
7	Daniel et al. (2021)	98	Assess impact of online CBM-I on mobility patterns using passively collected mobile sensing data	RCT	GPS location data (length of homestay, time spent at others' houses, location entropy, circadian movement)	No systematic intervention effects on passive mobility patterns -> no success in shifting behavior in daily life	Robust framework to assess intervention effects in daily life or monitor client progress through passive GPS data collection

	References	Sample size	Aim of the study	Study design	Collected data	Effectiveness outcomes	Feasibility outcomes & participant impressions
8	Otkhmezuri et al. (2019)	42	Examine feasibility of 3D VR CBM-I	Proof-of-concept semi-experimental study (between-subjects)	Immersion and presence experience, interpretation bias, emotional outcomes	Significant decrease in negative interpretation (t[41] = 4.7, p <.001), comparable with control group significantly stronger effects on anxiety in experimental group (F[1,40]=22.0, p<.001)	higher degree of immersion (F[5,36]=20.9, p<.001) and presence (t[40]=4.75, p<.001)
9	Salemink et al. (2022)	79	Examine if gamification makes interpretation training more engaging and enjoyable	2x2 between-subjects design	Training task evaluation, interpretation bias	Both gamified and standard CBM-I successful in increasing positive interpretations compared to placebo (F[1,73]=6.1, p=.02) according to recognition task, but according to scrambled sentence test no significant increase in positive interpretations in gamified CBM-I group (t[43] = -0.64, p <.53) Gamified CBM-I did not significantly reduce anxiety (F[1,65]=1.0, p=.032), but neither did standard CBM-I	More enjoyable and engaging (F[1,73]=5.3, p=.03.)

	References	Sample size	Aim of the study	Study design	Collected data	Effectiveness outcomes	Feasibility outcomes & participant impressions
10a	Schmidt & Vereenooghe (2021)	71	Evaluate efficacy of online CBM-I intervention	Pilot RCT	Hostile interpretation bias, aggression, emotional and behavioral problems, peer victimization	Significant reduction of hostile attributions ($t[34] = 6.782$, $p < .001$) and reactive aggression only in the experimental group ($t[34] = 4.957$, $p < .001$)	Not applicable
10b	Schmidt & Vereenooghe (2021)	23	Explore acceptability of the intervention	Focus groups	Training likeability, adherence, user experience, expectations, and barriers to participation	Not applicable	High likeability of training content and delivery (100% of participants), good training adherence (88% completed all three sessions), overall experience perceived as fun (87.5%), request for longer and more frequent training sessions, no barriers to participation
11	Weisberg et al. (2022)	40	Examine feasibility, acceptability, and efficacy of personalized, transdiagnostic CBM intervention	Pilot RCT	Interpretation bias, anxiety symptoms, feasibility (by treatment completion), acceptability,	Significant reduction in threat interpretations compared to control group ($F[1,17]=12.61$, $p=.002$), 55.6% of experimental group experienced a 20% reduction in anxiety symptoms (benchmark 50%)	Satisfaction M=29.78, SD=2.87 (benchmark = 24) Feasibility: 71.43% completed ≤6 interventions (benchmark: 70%)

Note: 3D VR = three-dimensional virtual reality, RCT = randomized controlled trial

Table 4

Technology and intervention design

	References	Type of technology	Role of technology	Benefit of the use of technology	Intervention design	Human-technology interplay
1	Beard et al. (2021)	Smartphone app (HabitWorks)	Delivery	Option to extend care through the high-risk month post discharge	Daily sessions during acute treatment phase, 3 sessions a week during transition phase (from hospital discharge to outpatient care)	Blended care (adjunct to acute psychiatric care)
2	Beard et al. (2022)	Smartphone app (HabitWorks)	Delivery	Customizable scheduling of exercises, personalization	App use 3 times per week for 1 month	Stand-alone treatment
3	Boukhechba et al. (2018)	Mobile sensing (heart rate and accelerometer data) and experience sampling via smartphone and smartwatch	Measurement	Eliminates self-report bias and burden in outcome measurements, could in the future inform Just-in-Time interventions	3 weeks in total. Continuous passive data collection, each day up to 7 short ESM questionnaires Week 2: 6 times 10min CBM online training session	Stand-alone measure (substitute for self-report measurements)
4	Burley et al. (2020)	Smartphone app: MindTrails program	Delivery	Personalization of training content and implementation of intentions and goal setting	5 training sessions with five-day break in between each session	Stand-alone treatment
5	Nieto & Vazquez (2021)	Online intervention package (audiovisual format) including videos, tasks, and exercises	Delivery	Not specified	4 sessions over the course of 10 days	Stand-alone treatment

	References	Type of technology	Role of technology	Benefit of the use of technology	Intervention design	Human-technology interplay
6	Daniel et al. (2020)	Ecological momentary assessment via smartphone app MetricWire	Measurement	Attain ecological data and evaluate how intervention affects daily life	5-week smartphone monitoring study (6 surveys per day); 6x15min online CBM-I sessions during week 3	Blended (complementary tool in outcome monitoring)
7	Daniel et al. (2021)	Passively collected mobile sensing GPS data via smartphone	Measurement	Unobtrusive, in-the-moment data collection; minimal client and clinic burden; treatment monitoring instead of solely after treatment measures, measure actual behavior	5-week passive mobile sensing data collection; 6x15min online CBM-I sessions during week 3	Blended (complementary tool in outcome monitoring)
8	Otkhmezuri et al. (2019)	Mobile-based stereoscopic 3D VR	Delivery	Activation of threat-related memory schema through immersion and therefore possible boost of CBM-I effect; improvement of user experience and adherence through less monotonous exercises and a more attractive layout	One in-lab session	Stand-alone treatment
9	Salemink et al. (2022)	Computer game including gamification elements (points system, adaptiveness, indirect competition, enjoyable elements,	Delivery	More engaging, enjoyable, and motivational through gamification	One in-lab session	Stand-alone treatment

	References	Type of technology	Role of technology	Benefit of the use of technology	Intervention design	Human-technology interplay
		sound effects, and rules and goals				
10a	Schmidt & Vereenooghe (2021)	Online training including animated videos, cartoon pictures and a narrating and entertaining avatar	Delivery	Adjust for processing deficits (reduce cognitive and reading demands by implementing audio-voiceover and animated videos; enhance motivation and concentration through entertaining avatar and feedback)	3 online sessions, 10-15min each, once a week	Stand-alone treatment
10b	Schmidt & Vereenooghe (2021)	“	“	“	"	“
11	Weisberg et al. (2022)	Online intervention Mental Habits, including instructional videos, personalization process, CBM sessions, dashboard for monitoring and communicating patient progress	Delivery (and monitoring)	Personalization, linkage to primary care through monitoring and communication features	8 sessions in total, 2 sessions per week. first sessions in primary care with the coach.	Blended care

Discussion

This scoping review summarizes recent scientific literature on the use of technology in CBM-I. Eleven articles covering twelve studies published between 2018 and 2023 were reviewed. These articles were examined for participant characteristics, study characteristics and outcomes, and technology and intervention designs.

Main findings

The focus of our first research question was on the participant groups and psychological conditions targeted by CBM-I interventions. It was noticeable that most participant groups showed anxiety symptoms with social anxiety being the condition targeted the most, which is comparable with other reviews on both CBM and mobile mental health that also identified samples with anxiety diagnoses as the most common target (Ding et al., 2023; Martinelli et al., 2022). As indicated by Ding et al. (2023) this focus corresponds to present research priorities of youth mental health services. Depressive symptoms were only mentioned in two studies. This might be surprising, considering that earlier reviews and meta-analyses identified that 10% (Martinelli et al., 2022) or 33% (Cristea et al., 2015) of the reviewed studies dealt with participants with depressive symptoms. Jones and Sharpe (2017) stated that 58% of the meta-analyses on CBM they reviewed assessed depressive symptomology. However, they revealed that CBM did not successfully reduce depressive symptoms while eliciting significant reductions of anxiety symptoms (Jones & Sharpe, 2017). Martinelli et al. (2022) moreover concluded that bias reduction in depressed individuals was more successful when applying ABM than CBM-I. Social anxiety, on the other hand, seemed to be the symptom type with the largest effect sizes in CBM-I (Martinelli et al., 2022) which is in line with the current finding that individuals with social anxiety were targeted most often by technologically supported CBM-I interventions.

For the second research question we extracted the collected data and the reported feasibility and effectiveness outcomes. The reviewed studies were quite heterogenous in their outcomes of interest with some examining reduction of anxiety or depression symptoms, others assessing change in interpretations while again others focused on feasibility and usability of technological innovations. While measured effects of the CBM-I interventions on targeted conditions yielded mixed results, feasibility and usability measures of all reviewed studies were mostly positive, which is in line with an earlier review on emerging eHealth interventions for individuals with mental illnesses that reported high feasibility and acceptance of interventions but heterogenous clinical outcomes (Naslund et al., 2015). Although anxiety symptoms were successfully reduced most of the time, it must be noted that mostly pilot studies and open trials reported significant reductions. Thus, these results must be interpreted with care. The reduction of depressive symptoms was only clinically relevant in one of two studies. However, in this study, improved symptomology could only be shown right after the treatment, while in a 1-month follow-up, depressive symptoms have even worsened compared to baseline level (Beard et al., 2021). A possible explanation for this finding is that the mere participation in the study and utilization of the app that has been rated satisfactory evoked feelings of mastery and reward in participants. Thus, study participation itself could have impacted depressive symptoms through behavioral activation, rather than CBM-I (Chartier & Provencher, 2013). Alternatively, considering that the study was a non-controlled open trial with a within-subjects pre-post design, it is important to acknowledge that other factors, such as the timing of the study, could have distorted the results. As the intervention took place during the acute treatment phase of patients in a behavioral health partial hospital (Beard et al., 2021), the decrease in depressive symptoms could have been caused by other therapeutic measures while the increase in the follow-up could have been related to the heightened risk of relapse during the first three months after discharge (Woo et al., 2006).

The third research question dealt with the type and role of technology in the interventions. In most studies, technology was applied in the delivery of the CBM-I intervention while in only three studies, technology was used to measure intervention effects. The delivery of CBM-I interventions most often took place via multimedia online programmes and smartphone apps which aligns with a recent review on mobile mental health interventions which reported a 36% proportion of interventions being delivered via web page and a 34% proportion via smartphone apps (Ding et al., 2023). Considering not only apps but also mobile sensing and ecological momentary assessment, smartphones were the most frequently used technological tool. This is reasonable, given that most adults are in possession of a smartphone which makes it an accessible tool, in contrast to, for example, VR technology whose implementation in treatment requires specific equipment and training (Maples-Keller et al., 2017; Pew research center, 2021). In the measurement of CBM-I interventions, smartphones have predominantly been studied in the context of passive mobile sensing with one study collecting GPS data to measure intervention effects on mobility behavior and another study collecting and correlating accelerometer data and heart rate to measure stress levels. Although different reviews point out insufficient study quality and questionable methodologies in the existing literature on passive mobile sensing, they do recognize passive mobile sensing in mental health as an auspicious opportunity to make use of the gigantic amounts of data smartphones and smartwatches continuously produce (Mohr et al., 2017; Seppälä et al., 2019; Trifan et al., 2019).

The fourth research question explored the intervention designs and the dynamics of the human-technology interplay. The variety of intervention designs in the reviewed studies was large and there was no consensus on the number and frequency of training sessions within CBM-I interventions. This is in line with the systematic review of meta-analyses by Martinelli et al. (2022) that reported difficulties in interpreting results due to the high variance among experimental designs. Due to differences in several characteristics between the studies, the only conclusion that can be drawn is that the optimal frequency and number of training sessions have not been determined yet. Regarding the human-technology interplay, most of the reviewed studies examined interventions that were intended as stand-alone treatments. This is not surprising, as facilitated access to mental health services has widely been acknowledged as a main advantage of applying technology in mental health care (Griffiths & Christensen, 2007; Hollis et al., 2015; Topooco et al., 2017). Christensen and Hickie (2010) argue, that a focus on blended treatment instead would annihilate the opportunity of offering efficient and cost-effective treatment to a broader target group and Jorm et al. (2013) point out that supplying patients with milder problems with digital stand-alone treatments would leave skilled clinicians more capacity to work with more complex cases. Accordingly, developments in the field of CBM-I seem to go in a similar direction and aim at making treatment more accessible.

The last research question dealt with the benefits the interventions achieved through the implementation of technology. As diverse and numerous as the intervention characteristics and technological approaches were the benefits highlighted in the reviewed studies. A recurrent theme was an increase in user experience and the prospect to make CBM-I more enjoyable, which builds on earlier findings of traditional CBM being perceived as boring and monotonous (Beard et al., 2012) and calls to work out more enjoyable trainings with higher acceptability (Jones & Sharpe, 2017). In addition, the possibility of personalizing training content through technology has been mentioned several times. However, with the exception of Burley et al. (2020) who assumed a lifting effect on user engagement, no study expounded their reasons for enabling personalization. This is in line with a recent review on personalization strategies in digital mental health interventions in which the authors reported a lack of clear scientific evidence for the benefits of personalization (Hornstein et al., 2023). Other reported benefits included the enhanced effectiveness of CBM-I through the immersion into seemingly realistic scenarios through virtual reality and the associated activation of schemata, as well as the enhanced accessibility through adjusting for cognitive deficits with audio-voiceovers and animations that replace text-based scenarios. In the measurement of CBM-I, technology was mostly attributed the benefits of eliminating burden and bias and unobtrusively attaining data about actual intervention effects in daily life. One study highlighted the opportunity to build on the current research on mobile sensing measurements to inform just-in-time interventions, an emerging type of interventions oriented towards the changing needs of individuals during their daily life (Wang & Miller, 2020). For CBM-I interventions this would entail delivering training exactly in situations when high mental stress is measured, and participants might, for example, be moments before the onset of a panic attack (Boukhechba et al. 2018).

Limitations

The findings in this report are subject to certain limitations. All steps during the selection and extraction process were conducted by only one reviewer. This handling deviates from common recommendations, which emphasize the involvement of at least two reviewers (Levac et al., 2010; Peters et al., 2015). As a result, inter-rater reliability cannot be guaranteed and the potential for bias cannot fully be mitigated. Next, as this review does not update an earlier review, the year limit of included articles is chosen arbitrarily. It was set as the focus on technology makes it likely that older studies are outdated. However, it cannot be ruled out that articles published before the cut-off year could have been of interest. Moreover, in relation to the number of studies that were focused on, the scope of different kinds of technology, outcome measures, and especially intervention designs was relatively large. It is, therefore, difficult to recognize patterns and draw conclusions about, for example, the feasibility of a certain type of technology. Lastly, the general scope of studies on technology in CBM-I was limited. Within the twelve studies, three researchers appear twice as first author, meaning that only nine different first authors are represented in this review, while some other contributors are also represented multiple times. Thus, the variety of researchers interested in this topic might be limited, which could affect the generalizability of results. Since this review maps out a new field of interest with only recent articles and does not build on an earlier review, it is unclear, if the field of research is growing, but still in its infancy, or if research on technologically supported CBM-I has been conducted more in the past but has ceased due to unsatisfying intervention effects.

Implications and directions for future research

As a scoping review, this review outlined the extent of the current scope of research about technology in CBM-I. As, due to the nature of this review type, studies of different study designs were included and no quality appraisal has been conducted, no generalizable, but only preliminary conclusions on the effectiveness of studied interventions can be drawn. Although a systematic review or meta-analysis could establish more clarity, it is questionable whether the scope of available research offers enough ground for such analyses. However, this review opened the research field by discovering questions that remain unanswered and need clarification for the implementation of technology in CBM-I to further develop.

First, as this review showed, there is no consensus on optimal intervention designs in CBM-I. The reviewed studies examined interventions with substantial heterogeneity in terms of the number and frequency of training sessions. Moreover, most of these studies did not provide explicit justification for their design choices. Thus, future research could focus on clarifying the fundamental conditions under which CBM-I works best to create solid ground for future technological interventions. This would also be in line with the recommendations by Kuckertz and Amir (2017) who invoked future research to ask focused questions and differentiate between different conditions, instead of assessing if CBM-I is effective under all conditions.

Next, future research should investigate the role of different measurement tools. The current review discovered two cases where effectiveness outcomes on interpretations could only be shown with a certain measurement tool, but not with another one. In both cases, the measurement tool that did find an effect was arguably more similar in nature to the CBM-I training task (Nieto & Vazquez, 2021; Salemink et al., 2022). This might mean that the training does not necessarily promote more positive interpretations, but that participants possibly solely get better at the training. Further research should investigate the validity of applied measurement tools and where appropriate aim to develop new valid measurement tools. To go a step further, future reviews should focus on measurement tools that have been applied in earlier CBM-I studies to find further patterns and possible explanations for allegedly found clinical effects.

Conclusion

The current review has provided an overview of the scope of research on technology in CBM-I. It was the first one to cover the complete bandwidth of technological tools and innovations and contemplate their characteristics regarding the type of technology, their role in the intervention, the dynamics of the human-technology interplay, and the benefits of their implementation. This review demonstrates that technologically delivered or measured CBM-I interventions are mostly feasible and capable of offering convincing benefits over conventional CBM-I, although there is a need for further research on the conditions under which they achieve clinical effectiveness. While so far, the extent of research in this area is scarce, this review offers a sound starting point and concrete recommendations for further research.

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