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Towards implementation of cognitive bias modification in mental health care: State of the science, best practices, and ways forward

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ABSTRACT

Cognitive bias modification (CBM) has evolved from an experimental method testing cognitive mechanisms of psychopathology to a promising tool for accessible digital mental health care. While we are still discovering the conditions under which clinically relevant effects occur, the dire need for accessible, effective, and low-cost mental health tools underscores the need for implementation where such tools are available. Providing our expert opinion as Association for Cognitive Bias Modification members, we first discuss the readiness of different CBM approaches for clinical implementation, then discuss key considerations with regard to implementation. Evidence is robust for approach bias modification as an adjunctive intervention for alcohol use disorders and interpretation bias modification as a stand-alone intervention for anxiety disorders. Theoretical predictions regarding the mechanisms by which bias and symptom change occur await further testing. We propose that CBM interventions with demonstrated efficacy should be provided to the targeted populations. To facilitate this, we set a research agenda based on implementation frameworks, which includes feasibility and acceptability testing, co-creation with end-users, and collaboration with industry partners.

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Over the past two decades, cognitive bias modification (CBM) has evolved from a method to experimentally test psychological mechanisms hypothesized to play a role in mental health disorders to a candidate intervention for the treatment of some disorders. While we are still discovering the conditions under which clinically relevant effects occur, the public health need for low-cost and accessible mental health tools calls for preparation for implementation (see Kazdin & Blase, 2011). Unlike standard cognitive-behavioral interventions which require adaptation to a digital format, CBM is digitally native. The digital format in particular increases the potential of CBM to benefit hard-to-reach populations, such as individuals who are unable to access traditional evidence-based psychotherapy (e.g., those living in rural areas). In some cases, CBM may allow for standalone application (or: self-management) against limited time-investment and costs and great flexibility for the patient. CBM is believed to exert its effect via the modification of relatively automatic processes (Blackwell, 2020), which sets it apart from most other cognitive interventions, which tend to operate on top-down, controlled processes. In this way, CBM addresses a mechanistic niche that is not addressed by other available digital interventions.

We are a group of 18 authors representing 6 countries, with 25 years of experience in conducting cognitive bias modification (CBM)-related research including >100 clinical trials impacting >3000 participants around the globe (see e.g., Fodor et al., 2020; Wiers et al., 2023). Our expertise lies in the mechanisms, development, and implementation of CBM. This paper is the product of round table and panel discussions during the 2023 conference of the Association for Cognitive Bias Modification (ACBM) hosted by the National Institute of Mental Health in Washington, D.C., United States of America. A major theme of the conference was discussion and debate around the readiness of CBM for implementation, the advantages and drawbacks of expediting or delaying implementation and dissemination, and important future directions for the field as a whole. In this position paper, we summarize and expand upon the ideas shared at the 2023 conference to offer a high-level synthesis of our perspective on the field of CBM as a whole, with particular attention to issues of readiness, priorities for, and barriers to the dissemination and implementation of various CBM interventions. Specifically, we discuss the state of CBM as a clinical tool for three common and costly forms of psychopathology: anxiety, depression, and substance use disorders (SUD[1]; Effertz & Mann, 2013). We focus on the interventions with the largest empirical bases: attentional bias modification (AtBM), interpretation bias modification (CBM-I), and approach-avoidance bias (or: action tendency) modification (ApBM[2]). We further identify practical and scientific frontiers including future directions to move CBM towards successful and sustainable implementation in mental health care.

1. A brief history of CBM paving the way for its future as a clinical tool

Almost half a century ago, researchers started developing experimental paradigms to investigate cognitive biases - or biases in information processing - related to mental health problems. To use attentional bias as an example, the hypothesis that anxious individuals show hypervigilance to threat was tested using an experimental task designed to measure attentional orienting (and later, also disengagement). New tasks were developed, such as the visual probe task, to study attentional bias (MacLeod et al., 1986), and old tasks such as the Stroop-task were modified with the same goal (Williams et al., 1996). Early meta-analytic results suggested that attentional bias was related to clinical problems including anxiety (Bar-Haim et al., 2007), depression (Peckham et al., 2010), and substance use (Field et al., 2009). Although methodological improvements in the field later raised concerns regarding the robustness and interpretability of these early tasks (McNally, 2019; Parsons et al., 2019), clinical observation, theoretical models, and later studies using measures with stronger psychometric properties nevertheless continue to broadly align with these general observations (Loijen et al., 2020; Mogg & Bradley, 2018; Songco et al., 2020).

While there is broad support for theoretically-predicted correlations between mental health problems and various cognitive biases (e.g., Beck, 1976; Beck & Haigh, 2014; Clark, 1988; Clark & Wells, 1995; Toneatto, 1995; Wright et al., 1993), observational studies cannot prove a causal relationship between the two. A strong test of a causal claim is an experiment, and this is how CBM originated: as an experimental method to test the hypothesized causal role of cognitive biases in the development of psychopathology. Two pioneering studies experimentally tested the effects of the manipulation of a cognitive bias in healthy volunteers: Mathews and Mackintosh (2000) manipulated interpretation bias in either a threatening or a benign way and found congruent effects on state anxiety across five experiments. MacLeod et al. (2002) did the same with an attentional bias for threat and found congruent effects on stress reactivity. Following these seminal studies, other biases were manipulated in a similar way; for example, approach bias in substance use (e.g., Wiers et al., 2010). Such experimental manipulation studies represent the necessary first step in the experimental medicine approach to intervention development: testing a putative target in healthy volunteers (Sheeran et al., 2017).

After a number of CBM studies in healthy volunteers suggested that cognitive biases could be experimentally manipulated and training-congruent effects on disorder-relevant symptomatology observed, clinical researchers began to study CBM as a clinical tool, the next phase of intervention development (Sheeran et al., 2017). As depicted by intervention development and evaluation frameworks (e.g., Ehring et al., 2022; Skivington et al., 2021), the first consideration of clinical effectiveness is: Does CBM reduce symptoms in the short-term under controlled conditions relative to a suitable comparison condition in a population with clinical symptoms (i.e., in a randomized trial comparing a positive to a sham condition)?

The first randomized controlled trials (RCTs) in clinical samples were conducted in anxiety (e.g., Amir et al., 2009; Schmidt et al., 2009), depression (e.g., Koster & Hoorelbeke, 2015; Vrijsen et al., 2018), and alcohol use disorders (e.g., Schoenmakers et al., 2010; Wiers et al., 2011). In some of these studies, CBM was an add-on to "treatment as usual"; for example, in a series of studies testing the add-on effect of approach bias modification (see Wiers et al., 2023 for a review), while other studies probed its potential efficacy as a stand-alone tool (Amir et al., 2009). Results from these studies were mixed but included enough positive findings to suggest the potential value of CBM in clinical contexts.

When synthesizing the current state of the literature, it is important to distinguish between experimental proof-of-principle studies in healthy and analogue samples (goal: manipulate bias and test causality) and clinical applications (goal: lasting reduction of symptoms). As our present focus is on readiness for implementation in the clinical setting, we focus on clinical (diagnosed and/or treatment-seeking) samples. In addition, although a clear understanding of mechanisms of change and *target engagement* (the extent to which the targeted cognitive process has been affected, here: change in bias) is not required for clinical efficacy, it is theoretically relevant with implications for targeted intervention (i.e., precision medicine, Ginsburg & Phillips, 2018). We therefore also evaluate the evidence for bias change as the mechanism for symptom change. This consideration is aligned with the experimental medicine

[1] Alcohol use disorder is the only substance use disorder with a sufficient number of studies in clinical samples to warrant a review. There is a growing literature on CBM for tobacco use, but this work has been conducted mostly in non-clinical samples, with largely null results in clinical samples (Wittekind et al., 2024-a).

[2] Approach bias modification has also been abbreviated as ABM; to avoid confusion we distinguish between AtBM and ApBM (cf., Rinck et al., 2018).

approach to intervention development (Sheeran et al., 2017). Indeed, some theorists have argued that symptoms should change only when bias is reduced (Grafton et al., 2017), though this is not always the case as measurement issues may qualify this conclusion (e.g., Rinck et al., 2018). In addition to efficacy and bias change, there are other central aspects to implementation (e.g., feasibility, adherence) that have hardly been considered in the CBM field but could serve as items in future implementation efforts of CBM. Such criteria and ways forward are discussed at the end of the paper.

2. Evaluating readiness for clinical implementation for CBM types and target populations

We briefly synthesize the state of the literature on three major forms of CBM: AtBM, CBM-I, and ApBM. The CBM field includes other approaches (such as imagery-based CBM, e.g., Blackwell et al., 2015; CBM-Memory, e.g., Vrijsen et al., 2023; selective inhibition, e.g., Stein et al., 2022; cognitive control training, e.g., Verdejo-Garcia et al., 2022), but currently their clinical empirical base is too limited to be included here. As an independent and international scientific society, we offer a

Attentional Bias Modification		
Anxiety		
	Criterion	**Evidence**
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**yes**
	Few or no null findings from meta-analyses	**no**
	Real-world effectiveness demonstrated	**insufficient data**
	No evidence of adverse effects	**yes**
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**insufficient data**
	Few or no null findings from meta-analyses or high-quality studies	**no**
	Dose-response established	**insufficient data**
Depression		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**yes**
	Few or no null findings from meta-analyses or high-quality studies	**no**
	Real-world effectiveness demonstrated	**no**
	No evidence of adverse effects	**insufficient data**
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**no**
	Few or no null findings from meta-analyses or high-quality studies	**no**
	Dose-response established	**no**
Substance use disorder		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**Smoking: no** **Alcohol: insufficient data**
	Few or no null findings from meta-analyses	**insufficient data**
	Real-world effectiveness demonstrated	**no**
	No evidence of adverse effects	**Smoking: insufficient data** **Alcohol: yes**
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**insufficient data**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	Dose-response established	**insufficient data**
Interpretation Bias Modification		
Anxiety		

Fig. 1. Summary of the state of the literature of Cognitive Bias Modification (i.e., Attentional-, Interpretation-, and Approach Bias Modification) for anxiety, depression, and substance use disorder with respect to efficacy, mechanism, and overall readiness for implementation.
Note regarding the criteria: We considered whether meta-analyses or multiple high-quality studies suggest that the intervention produces symptom improvement or change in the target mechanism (e.g., attentional bias in AtBM) versus a control condition ("yes" = meta-analyses or >1 high-quality studies produced evidence). A "yes" for the state and quality of null findings criteria required that there be few or no meta-analyses (or high-quality studies) that failed to find an effect of the intervention on symptoms or the target mechanism. A "yes" for the evidence of efficacy in real-world (non-laboratory) contexts means sufficient evidence exists. A "yes" on the criterion for no clinically significant adverse events means none were reported in the literature. Finally, we determined whether the literature was broadly suggestive of a dose-response relationship ("yes" = such evidence exists).

	Criterion	Evidence
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	yes
	Few or no null findings from meta-analyses or high-quality studies	yes
	Real-world effectiveness	insufficient data
	No evidence of adverse effects	yes
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	yes
	Few or no null findings from meta-analyses or high-quality studies	yes
	Dose-response established	insufficient data
Depression		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	yes
	Few or no null findings from meta-analyses or high-quality studies	insufficient data
	Real-world effectiveness	no
	No evidence of adverse effects	insufficient data
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	no
	Few or no null findings from meta-analyses or high-quality studies	no
	Dose-response established	insufficient data
Substance use disorder		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	insufficient data
	Few or no null findings from meta-analyses or high-quality studies	no
	Real-world effectiveness	no
	No evidence of adverse effects	insufficient data
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	no
	Few or no null findings from meta-analyses or high-quality studies	no
	Dose-response established	no
Approach Bias Modification		
Anxiety		
	Criterion	**Evidence**
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	no
	Few or no null findings from meta-analyses or high-quality studies	insufficient data
	Real-world effectiveness	insufficient data
	No evidence of adverse effects	yes

Fig. 1. (*continued*).

narrative consensus review grounded both in the published literature and in our experiences as researchers in this area, which afford us with insights into the gray literature, unpublished research, findings from pilot studies, and so on. This means we do not attempt to present a formal systematic review or meta-analysis. Many outstanding and highly rigorous systematic reviews and meta-analyses of different kinds of CBM interventions have been published already, and we cite and draw heavily on this work in reaching our conclusions. Instead, we explicitly present our expert opinion, and we encourage readers to consider our conclusions and recommendations through that lens.

Fig. 1 summarizes our perspective on the state of the literature for each intervention procedure (i.e., type of CBM) with respect to efficacy, mechanism, and overall readiness for implementation. We considered readiness in terms of several criteria. First, we considered whether meta-analyses or multiple high-quality studies suggest that the intervention produces symptom improvement versus a control condition. We favored meta-analyses in making these determinations, but also evaluated the literature on a study-by-study basis where conclusive published meta-analyses were not available or were outdated (i.e., additional high-quality trials since published). High-quality studies were operationalized as those meeting at least three of the following criteria: statistical power $\geq$80% to detect a medium effect for a difference between groups; inclusion of an appropriate control condition (e.g., no-contingency sham training); clear conceptualization and aims; and use of open science practices (e.g., preregistration; open data). We favored these custom criteria over published quality checklists such as the Cochrane Risk of Bias 2 because deviations from such checklists (e.g., participants not masked to condition) often reflect intentional decisions by CBM researchers to probe a specific theoretical or clinical question, rather than lack of rigor.

Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**no**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	Dose-response established	**no**
Depression		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**insufficient data**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	Real-world effectiveness	**yes**
	No evidence of adverse effects	**insufficient data**
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**insufficient data**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	Dose-response established	**no**
Substance use disorder		
Symptom outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**Smoking: no** **Alcohol: yes**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	No evidence of adverse effects	**yes**
	Real-world effectiveness	**Smoking: no** **Alcohol: yes**
Mechanism outcomes	*Meta-analyses or multiple high-quality studies find an effect*	**insufficient data**
	Few or no null findings from meta-analyses or high-quality studies	**insufficient data**
	Dose-response established	**no**

Note regarding the criteria: We considered whether meta-analyses or multiple high-quality studies suggest that the intervention produces symptom improvement or change in the target mechanism (e.g., attentional bias in AtBM) versus a control condition ("yes" = meta-analyses or >1 high-quality studies produced evidence). A "yes" for the state and quality of null findings criteria required that there be few or no meta-analyses (or high-quality studies) that failed to find an effect of the intervention on symptoms or the target mechanism. A "yes" for the evidence of efficacy in real-world (non-laboratory) contexts means sufficient evidence exists. A "yes" on the criterion for no clinically significant adverse events means none were reported in the literature. Finally, we determined whether the literature was broadly suggestive of a dose-response relationship ("yes" = such evidence exists).

Fig. 1. (*continued*).

Next, we assessed the state and quality of null findings. A "yes" for this criterion in Fig. 1 required that there be few or no meta-analyses (or high-quality studies, where meta-analyses were not available) that failed to find an effect of the intervention on symptoms. Theoretical concerns have recently been raised about the expectation that learning from computerized training contexts will spontaneously generalize to ecological contexts (Blackwell, 2020; Hallion et al., 2024). Moreover, delivery in real-world clinical contexts will occur outside of laboratory settings. We therefore investigated whether there was evidence of efficacy in real-world (non-laboratory) contexts. Finally, we confirmed that no clinically significant adverse events were reported in the literature.

We assessed mechanism engagement using similar criteria. First, we asked whether meta-analyses or multiple high-quality studies suggested a specific effect of the intervention on the mechanism (i.e., greater change in the mechanism in the active versus control conditions). Next, we assessed the state and quality of null findings as above. Finally, we determined whether the literature was broadly suggestive of a dose-response relationship (i.e., high-quality studies tending to find a correlation between change in mechanism and change in symptoms). Here also, we placed the greatest interpretational weight on meta-analyses, where available.

We preface our narrative synthesis by emphasizing that there is a fair amount of variability in the structure of each intervention across studies, particularly with regard to specifics (e.g., stimuli; number of trials). Where findings appeared robust to design variations, we offer recommendations at the level of the intervention as a whole. In cases where design variations appear to systematically impact either symptoms or mechanism, we caveat our recommendations accordingly. In each section, we briefly present findings from studies investigating these questions for each of three major CBM procedures: AtBM; CBM-I; and ApBM. Accompanying this narrative synthesis, we offer a summary of the extent to which each intervention engages its theoretically-identified mechanism and the readiness of each intervention for clinical implementation (see Fig. 1).

2.1. Therapeutic impact of attentional bias modification (AtBM) procedures

Anxiety and related disorders. Dozens of studies have investigated whether AtBM procedures, configured with the intention of reducing

attentional bias to anxiety-relevant information, can deliver therapeutic benefits for people suffering from a range of different anxiety disorders, including generalized anxiety disorder (GAD), social anxiety disorder (SAD), and additional related disorders including obsessive-compulsive disorder (OCD) and post-traumatic stress disorder (PTSD). Several meta-analyses suggest that such procedures can produce at least temporary improvements in anxiety symptoms compared to a control condition (e.g., Fodor et al., 2020; Jones & Sharpe, 2017), including in children (Hang et al., 2021). However, effect sizes tend to be small (Liu et al., 2017; Mogoaşe et al., 2014) and publication bias has been raised as a concern (e.g., Cristea, Kok, & Cuijpers, 2015; Hallion & Ruscio, 2011), leading other meta-analyses to conclude a null effect (Cristea, Mogoaşe et al., 2015). These inconsistent findings may be attributable in part to the relative unreliability of AtBM procedures for modifying attentional bias as intended (e.g., Martinelli et al., 2022). Moreover, challenges in creating reliable measures of attentional bias in turn raise challenges for the ability to establish clear links between bias change and symptom reduction (Parsons et al., 2019).

Major depressive disorder. We found only two studies meeting our criteria for "high quality" that investigated whether AtBM procedures, configured with the intention of reducing attentional bias to depression-relevant information, can deliver therapeutic benefits for people suffering from major depressive disorder (MDD; Hilland et al., 2018; Hsu et al., 2022). The profile of these studies alongside meta-analyses also including methodologically variable studies is one of inconsistent evidence of a resulting reduction in depressive symptoms (Hsu et al., 2022; Xia et al., 2023). Hilland et al. (2018) and Hsu et al. (2022) both found evidence of symptom reduction in preregistered studies of active (vs. sham) AtBM for remitted depressed and actively depressed adults, respectively. By contrast, smaller studies have typically failed to find an effect (Baert et al., 2010; Beevers et al., 2015; Krejtz et al., 2018), leading a recent meta-analysis to conclude insufficient evidence of an effect (Xia et al., 2023). The weakness of these findings may be attributable in part to, but cannot be entirely explained by, inconsistencies in the efficacy of AtBM procedures for changing attentional bias. While the AtBM procedure produced the intended change in attentional bias in Hsu et al. (2022), Hilland et al. (2018) did not find a significant effect. As for symptoms, smaller studies again often failed to show an effect (Baert et al., 2010; Woolridge et al., 2021).

Substance use disorder. Five studies have investigated whether AtBM reduces attentional bias to alcohol-relevant information and can deliver therapeutic benefits for people suffering from alcohol use disorder (AUD). In the largest CBM study to date, Rinck et al. (2018) combined AtBM and ApBM vs. sham-training in 1405 AUD patients, including three active conditions: six sessions of AtBM, six sessions of ApBM, and a mixed condition with three of each. Results were compared with corresponding sham conditions or no training. All three active CBM conditions showed to do better than sham conditions (8.4 % less relapse one year after treatment discharge), but effects on the targeted biases were small and did not mediate the clinical effect. In another high-quality study, Heitmann et al. (2021) performed a clinical RCT using a gamified version of AtBM in a mixed group of patients with either AUD or CUD (cannabis use disorder) and found no training effects on the bias or on clinical outcomes. Interpretation of the results from this study is complicated in part by the mixed nature of the sample and the variability of treatment goals (i.e., either reduction or abstinence).

Other well-designed studies in this area that nevertheless fall shy of our "high quality" criteria offer some further insights but are insufficient to draw strong conclusions. For example, in a study of 43 currently-abstinent adults undergoing inpatient treatment for AUD, Schoenmakers et al. (2010) found that such an AtBM procedure decreased length of stay in treatment and increased time to relapse. By contrast, Clerkin et al. (2016) did not observe clinical benefits following delivery of two AtBM procedures (one targeting anxiety and the other AUD) as a stand-alone intervention for 86 individuals with social anxiety and alcohol dependence, randomly allocated to four conditions.

In summary, while studies do not currently support the use of AtBM procedures for people diagnosed with MDD, there is some (albeit mixed) evidence that delivery of stand-alone AtBM procedures can produce therapeutic benefits for people with anxiety disorders, while adjunctive procedures show promise for those with AUD in abstinence-oriented treatment (for a review, see Wiers et al., 2023). The overall limited evidence for superiority of AtBM over control conditions using a 50-50% contingency may also be partly explained by putatively inert control procedures having therapeutic potency beyond placebo effects. Specifically, 50-50% control conditions might provide a low-dose intervention for individuals with strong attentional bias for threat or other disorder-related stimuli (Blackwell et al., 2017). Another point is that the capacity of AtBM procedures to deliver such therapeutic benefit shows signs of being linked to their success in eliciting the intended change in attentional bias. This suggests that it will be critically important for future researchers to develop AtBM procedures that reliably alter the target pattern of attentional bias, if consistent therapeutic benefits are to be obtained.

2.2. Therapeutic impact of interpretive bias modification (CBM-I) procedures

In this research, participants have commonly been exposed to training variants of interpretive bias assessment tasks, designed to reduce a target maladaptive interpretive bias. On each trial, participants are typically first presented with ambiguous information (typically words, sentences, or images) that can be interpreted in a negative or benign manner, and are then exposed to a training contingency designed to encourage them to impose the positive or benign interpretation on the preceding ambiguity. This training condition has typically been compared to a control condition in which there is no training contingency (positive and neutral trials equally likely) or conditions that do not train the process of interest (Blackwell et al., 2017).

Anxiety and related disorders. Several meta-analyses suggest that CBM-I procedures can produce improvements in anxiety symptoms compared to a control condition (Fodor et al., 2020; Jones & Sharpe, 2017). High-quality studies and meta-analyses investigating whether CBM-I procedures designed to reduce interpretive bias favoring threatening interpretations of ambiguity can deliver therapeutic benefits for people suffering from disorders such as GAD (e.g., Hirsch et al., 2020), SAD (e.g., Liu et al., 2017), and PTSD (e.g., Woud et al., 2021) (c.f. Jones & Sharpe, 2017). CBM-I typically shows a robust effect on bias, both in adults (Jones & Sharpe, 2017; Martinelli et al., 2022) and in youth (Krebs et al., 2018; Sicouri et al., 2023). In youth specifically, meta-analyses drew different conclusions with respect to effects on anxiety (Krebs et al., 2018; Sicouri et al., 2023). As all levels of symptoms (including unselected participants and studies of CBM-I as a preventative tool for youth without significant symptoms, e.g., Sportel et al., 2013; de Voogd et al., 2017; 2018) tend to be included in these meta-analyses, any clinical potential should therefore be interpreted with caution. Taken together, we conclude that CBM-I shows promise as a clinical intervention for adults with anxiety-related psychopathology, but that there is insufficient data to draw conclusions regarding the potential effects of CBM-I in youth.

Major depressive disorder. Only a few high-quality studies have investigated whether CBM-I procedures can deliver therapeutic benefits for people suffering from MDD (Gober et al., 2021). CBM-I studies for depression, typically configured with the intention of reducing interpretive bias favoring negative interpretations of ambiguity or increasing biases favoring positive interpretations, show promise with respect to clinical efficacy (Blackwell et al., 2015; Gober et al., 2021; Williams et al., 2015). CBM-I procedures designed to reduce negative or increase positive interpretations of ambiguity often successfully achieved bias reduction (Hirsch et al., 2018; Joormann et al., 2015; Williams et al., 2015), but there is less support from studies targeting other biases (e.g., hostile attribution bias; Smith et al., 2016).

Substance use disorder. We found only one published study (Cougle et al., 2017) investigating whether CBM-I can deliver therapeutic benefits for people suffering from AUD. In that study, trait anger was targeted, which could potentially attenuate alcohol use problems. There was evidence that the CBM-I procedure successfully modified the hostile interpretation bias, which led to reductions in trait anger. However, there were no clinical benefits of the CBM-I procedure in terms of a reduction in alcohol use within the time frame of the study.

In summary, there is preliminary support for the use of CBM-I procedures for people diagnosed with MDD and insufficient evidence to draw conclusions for use in AUD. However, there is good evidence that delivery of CBM-I procedures can produce therapeutic benefits for people with anxiety-related psychopathology.

2.3. Therapeutic impact of approach-bias modification procedures (ApBM)

Approach-avoidance training has existed conceptually since the 1960s, gaining popularity as an experimental therapeutic tool during the past decade (e.g., Wiers et al., 2010). Unlike AtBM and CBM-I, which are grounded in information processing theories of psychopathology, ApBM is grounded in motivational theories of psychopathology, and has consequently been applied primarily to disorders of maladaptive consumption, namely, eating disorders and SUD (particularly AUD). It shares with other forms of CBM the principle of leveraging reinforcement learning to bring biases (here, excessive or insufficient valuation) into more adaptive alignment. The total volume of studies is lower for ApBM compared to other CBM interventions, and major theoretically-grounded overhauls to the procedures have recently been proposed based on proof-of-principle studies regarding the underlying mechanisms (Wiers et al., 2020). Nevertheless, some conclusions can be drawn from the literature in its current state.

Anxiety and related disorders. Similar to standard exposure therapy, ApBM for anxiety has primarily aimed to increase approach toward feared but safe or desirable stimuli, such as faces in SAD (Bomyea et al., 2023; Rinck et al., 2013) or contamination-related stimuli in OCD (Amir et al., 2013; Weil et al., 2017). ApBM has also been investigated as an intervention to facilitate avoidance of compulsion-related stimuli, such as hair in trichotillomania (Maas et al., 2018). However, ApBM has received less empirical attention than other types of CBM for anxiety-related psychopathology (including obsessive-compulsive and related disorders), and we found no studies in clinical samples that met our criteria for "high quality." Conclusions from a review (Loijen et al., 2020) suggest no clinical advantage for ApBM over sham training, suggesting that observed improvements may be attributable to nonspecific factors. However, we suggest that there are too few studies to observe clear patterns in training or sample characteristics as predictors of response. Taken together, we do not consider ApBM for anxiety and OCD or related disorders to be indicated for clinical use at this time.

Major depressive disorder. ApBM in depression typically seeks to increase the approach of positive stimuli, such as happy faces. Although the literature is small in terms of both number of studies and typical sample size of those studies, results to date seem promising. The only study determined to be high-quality according to our criteria (Vrijsen et al., 2018) found a beneficial effect of ApBM as an adjunct to treatment as usual (Vrijsen et al., 2018), with studies falling below our quality threshold also typically reporting positive effects for ApBM as an adjunctive treatment (Becker et al., 2019; Sweet et al., 2021) or stand-alone intervention (Bomyea et al., 2022). Taken together, ApBM for depression appears to be a promising area for future research, but the evidence base is not yet sufficiently strong as to recommend large-scale clinical implementation.

Substance use disorders. Evidence across several studies suggests that ApBM can help to reduce risk of relapse as adjunct to abstinence-oriented treatment of alcohol use disorders, with five well-powered ($N > 200$), high-quality studies all showing beneficial effects (Wiers et al., 2011; Eberl et al., 2013; Rinck et al., 2018; Manning et al., 2021, 2022; Salemink et al., 2022; review: Wiers et al., 2023).[3] There is some preliminary evidence for efficacy in highly impaired patients (e.g., in an open trial of ApBM for alcohol-dependent patients with Korsakoff's syndrome; Loijen et al., 2018). However, studies have typically not demonstrated effectiveness with outpatients with AUD (Laurens et al., 2023) or as a stand-alone intervention (Wiers et al., 2015, 2018). Evidence for a dose-response relationship is also ambiguous (Boffo et al., 2019; Loijen et al., 2020), with the only study to successfully demonstrate mediation between bias and symptom change also being one of the largest (Eberl et al., 2013). In contrast to alcohol, studies have not supported the efficacy of ApBM for smoking cessation (e.g., Wittekind et al., 2019; review: Wittekind, Rinck, & Wiers, 2024-a). More recent adaptations to ApBM include the use of personalized training stimuli (Garfield et al., 2021; Manning et al., 2021), contexts, and effect on personalized goals (Wiers et al., 2020). These aim to increase the ecological validity and adjust the intervention to changing insights regarding the underlying mechanisms (changes in automatic inferences regarding personal goals, rather than automatic associations, Van Dessel et al., 2019; Wiers et al., 2020) and show some preliminary evidence for changing alcohol use expectancies in healthy volunteers (Van Dessel et al., 2023). Taken together, the data are sufficiently strong to recommend use of ApBM alongside existing interventions to help reduce risk of relapse in AUD, although the mechanism of change remains unclear.

2.4. Additional conclusions on the readiness for clinical implementation for CBM

The current data indicate that we cannot draw conclusions about the clinical efficacy of CBM as a whole, but that consistent patterns emerge dependent on the type of clinical disorder and training. Below we discuss the key findings and observations that go beyond the evaluation of a specific type of CBM. The first is our observation that many trials report high attrition rates (e.g., Eberle et al., 2023; Heitmann et al., 2021; Ji et al., 2021). Boredom and a lack of confidence in the helpfulness of CBM could plausibly contribute to non-response and drop-out (Beard et al., 2012; Hohensee et al., 2020; Rozental et al., 2014). This highlights that acceptability and stakeholder involvement are important areas for future research while also indicating feasibility and adherence as challenges for real-world implementation trials.

The tightly-controlled, experimental nature of most CBM research is such that null findings compared to an active sham condition are not uncommon; however, even in these cases, we do not find evidence of harm. Although reports of adverse events are rare, this does not mean that risk of harm can be conclusively ruled out. Compared to interventions with documented adverse responses (e.g., increased risk of psychosis symptoms during mindfulness meditation; Van Dam et al., 2018); those that elicit distress during treatment (e.g., exposure therapy; Foa & McLean, 2016); or those that place high demands on the time or resources of patients (e.g., in-person psychotherapy for depression; Renn et al., 2019), CBM presents a comparatively low risk approach to intervention. Hampering this comparison is the fact that guidelines for reporting adverse events in trials on digital mental health interventions – as would be relevant for CBM – do not exist (Bergin et al., 2023). Limited reporting processes and difficulty recognizing adverse events in CBM trials (as well as for other digital interventions) hence likely contribute to minimal reports of adverse events.

CBM's overall low risk profile lowers the barrier for the minimum

[3] Note there is one as-yet unpublished negative trial on AtBM and ApBM as add-on to abstinence-oriented treatment for AUD (Spruyt et al., 2024). A training contingency was used below 90%, while all positive trials used 100% or 95% training contingency, suggesting that consistency is important in training.

necessary benefit (i.e., effectiveness) required to justify its use (Curran et al., 2012). CBM might figure as a cost-effective first step in a stepped clinical procedure, taking some patients out of the clinical range, thereby reserving limited face-to-face CBT resources for more severe cases (e.g., Pettit et al., 2017; Yeguez et al., 2020). Additionally, CBM can offer help in cases where an established first-line treatment is not available or not accessible. Note that this would of course not be advised in domains where stand-alone CBM has little merit, as in SUD. Based on the theoretical premises and empirical support for bias change being a mechanism of change of CBT and first-line antidepressant medication (Beck & Dozois, 2011; Harmer & Cowen, 2013; Vrijsen et al., 2021), CBM also has potential as an adjunctive or augmentation intervention where first-line treatment is not yielding sufficient relief from symptoms. CBM's augmenting effect on psychotherapy and pharmacotherapy deserves further examination (in line with e.g., Lazarov et al., 2018).

Another major theme is a lack of clarity regarding mechanisms. Even for procedures with good clinical outcomes (e.g., ApBM for abstinence-oriented AUD), the mechanism by which these changes occur is not clearly established. Several possible explanations for this ambiguity can be proposed. First, it is plausible that bias assessments are not sufficiently sensitive or reliable to capture true change in bias. This would be consistent with broader concerns regarding the psychometric properties of many assessment procedures (Kahveci et al., 2024; Kersbergen et al., 2015; Parsons et al., 2019). Relatedly, difference scores which are often used to capture the relative nature of cognitive bias in bias indexes come with their own psychometric concerns (i.e., decreased reliability; Leeb & Weinberg, 1977). Hence, efforts should be put towards capturing the theoretical process of bias without using difference scores e.g., by implementing eye-tracking. Second, the interventions may operate via mechanisms other than change in bias. The possibility of mediation by change in attentional control has been raised as a potential explanation for a lack of difference between active and sham training groups (e.g., Heeren et al., 2015); however, the plausibility of this interpretation has also been challenged (Hallion et al., 2024). The role of metacognitive processes (for example, the extent to which participants must - or cannot - be aware of the trained contingencies to achieve a clinical effect) is also debated (Grafton et al., 2014; Van Dessel et al., 2019). Although strong theoretical inferences require the demonstration of mediation by mechanism (Kazdin, 2007), these issues are less important with respect to clinical application. If the intervention shows no adverse effects and often helps, the question of how it achieves that goal is largely academic. Optimization of training, however, does require the identification of mechanistic pathways; this therefore remains an important goal for the field.

3. Agenda setting: how to facilitate implementation of CBM in mental health care?

Based on the current state of the empirical evidence it is important to consider the road towards implementation of effective, targeted, and timely use of CBM in clinical settings. Since 2000, the Medical Research Council in the UK has developed a systematic framework for developing and evaluating complex interventions, with the most recent revision occurring in 2021, which was jointly commissioned with the National Institute of Health Research (Skivington et al., 2021). These guidelines outline different steps for assessing interventions, which mostly follow the guidelines for new drugs. Based on these major implementation models and while providing specifications and additions relevant to CBM, we highlight some important ways in how CBM research can take steps to move towards implementation (see also Hallion et al., 2024).

Outcome selection. The frameworks ask for converging evidence of change on the 'target for transfer'. This means that the choice of outcome measures is central to evaluating its readiness for implementation. We acknowledge that this can be tricky for CBM; is disorder-specific symptom reduction the fitting outcome for this specific target population and treatment context, or should a more mechanistic and transdiagnostic outcome be selected (e.g., rumination/worry see Hirsch et al., 2020; Moritz et al., 2020)? The latter might yield stronger transfer effects, as it is often more closely related to the selected mechanistic target i.e., bias (see e.g., Vrijsen et al., 2023). This question is especially relevant to mental health care which is characterized by high comorbidity or multimorbidity, with proposed shared underlying mechanisms (cf. e.g., the negative valence system in the Research Domain Criteria (RDoC; Insel et al., 2010; Cuthbert, 2022).

Additionally, research could focus on the generation of stimulus material (personalized vs. generic stimuli, e.g., Kopetz et al., 2017), as modest effect sizes and null effect in previous CBM trails might be partly attributable to materials not being (optimally) relevant for the individual's target of concern. Research should also aim to identify the optimal dosing parameters, including number of trials, number of training sessions, and temporal spacing of training sessions. Intriguing findings on AtBM for social anxiety highlight the complexity of this issue and suggest a higher number of trials/sessions may paradoxically diminish training effects (Price et al., 2017), with also an indication of a similar effect in ApBM for AUD (Boffo et al., 2019). There is also a need to identify subgroups for whom CBM might be particularly effective within the clinical setting (i.e., moderators). In this vein, it has been shown that CBM might be particularly effective in individuals motivated to change (Wiers et al., 2018), and in individuals showing stronger biases at baseline (Eberl et al., 2013), though many trials have failed to replicate these findings.

In clinical practice and to aid our research agenda, selection of CBM protocol based on the patient's characteristics and preferences can be regarded as a form of personalized mental health care aided by shared decision-making (Drake et al., 2009), and monitoring bias- and symptom change to adjust the CBM protocol as a form of measurement-based care (Waldrop & McGuinness, 2017). In addition, new personalized approaches could be developed, based on an individual's own data and resulting symptom network (see Mansueto et al., 2023).

Feasibility, acceptability, and safety. The guidelines prescribe smaller-sized (pilot) trials to assess feasibility (recruitment rates), acceptability (participants' perceptions of helpfulness, usability) and safety considerations (including tolerability) of the intervention. Whilst most studies suggest CBM was acceptable in the populations it was tested, we know little about potential negative impacts (e.g., symptom deterioration, increased craving in the case of CBM for addictive disorders, or treatment dropout), warranting more research (for recommendations on internet interventions, see Rozental et al., 2014).

Involving stakeholders early on. To address whether a type of CBM is ready to be implemented also involves a closer look at the barriers and facilitators of use. This necessarily involves wider stakeholder engagement - including people with lived experiences (when looking to implement in clinical care, these are generally patients from the target setting and clinical group). Involving lived experience consultants in design decisions should help to improve engagement, retention, and satisfaction with the intervention, and therefore improve its chances of take up and potential effectiveness post-implementation (Schleider, 2023).

Specifically, we propose that CBM research should increasingly incorporate *Human-Centered Design* - an approach to interactive systems development to make them useable and useful based on the needs and requirements of users (Giacomin, 2014). Stakeholder involvement is crucial throughout the full design process (this is also referred to as co-creation and co-production), starting with an inquiry about specific needs of particular patient groups. It also entails identifying potential barriers of the intervention to address a specific need, as well as factors that are important in the design to facilitate use and uptake of the intervention. In most cases this will be an interactive and iterative process involving qualitative research methods, multiple design stages, and empirical research to study the outcomes and user experiences. Importantly, there are excellent guidelines to assist researchers in applying such strategies (for a review, see Seiferth et al., 2023).

The CBM field already has some strong showcases of qualitative approaches to CBM development and co-created interventions, identifying actionable steps to reduce attrition and increase satisfaction and usability. These examples include assessing anxious primary care patients' attitude towards CBM as well as its feasibility (Beard et al., 2012; Weisberg et al., 2022), the acceptability of CBM in psychosis (Leung et al., 2019) and OCD (Falkenstein et al., 2022), and co-created CBM-based interventions that are ready to disseminate (e.g., https://mindtrails.virginia.edu/ see Larrazabal et al., 2024; https://www.habitworks.info/ see Beard et al., 2021).

Providing a rationale and psychoeducation. Within initial experimental CBM research, oftentimes no rationale was provided to limit expectancy or placebo effects. This allowed for a clearer mechanistic understanding of the causal influence of training a particular cognitive operation. Although this reasoning is legitimate from an experimental perspective, in many clinical contexts the goal is to achieve maximum transfer of training of a specific cognitive operation (i.e., transfer occurs between a training task and novel tasks or situations that are thought to be tapping into a similar cognitive operation). One interesting approach, therefore, is to explicitly leverage providing a rationale for CBM, psychoeducation, and incorporation of real-world practice to achieve better generalization of learning, and hence stronger transfer of CBM to cognitive biases in different daily life contexts.

In fact, in recent years, thinking about CBM has shifted from trying to manipulate a cognitive operation through an implicit training task to using CBM principles to increase awareness of problematic negative biases and to encouraging top-down control over such biases (e.g., Lazarov et al., 2018; Sanchez et al., 2015), in line with the changed perspective on the mechanisms underlying ApBM (Van Dessel et al., 2019; Wiers et al., 2020). Indeed, initial research into this topic suggests that patients' perceptions of an attentional bias training program in socially anxious individuals predicted symptom reduction as well as change in attentional bias (Kuckertz et al., 2019). In fact, a co-creation procedure with individuals with hazardous alcohol use and social anxiety concluded that a compelling rational and psychoeducation should increase engagement with CBM (Prior et al., 2020).

Potential for scale-up. We have to assess whether the specific type of CBM reaches, engages and retains the clinical target group (including people from marginalized groups). We acknowledge that so far CBM research has oversampled from WEIRD (i.e., White, Educated, Industrialized, Rich, and Democratic) populations, leaving us to first request research in diverse including minoritized groups before we can substantiate implementation efforts in non-WEIRD populations.

For all target populations, important questions for scale-up are: Do those who deliver it adhere to the application protocols (fidelity); do those whom it is delivered to adhere to intervention requirements (adherence) (e.g., are instructions on dosage and where (e.g., quiet room) to do the training being followed); and is it readily taken up by CBM deliverers such as clinical professionals and services (adoption)? These criteria ought to be assessed from the outset of CBM development and ideally be nested in subsequent stages too (e.g., within efficacy or effectiveness[4] and possibly effectiveness-implementation hybrid trials (Curran et al., 2012)) keeping the requirement of the target population and setting in mind.

Stable funding. A common obstacle for implementation of especially digital interventions is a lack of stable funding for necessary technical support and further development of the tool. When the research funding ends, often the platform/tool cannot be maintained (the "valley of death" in design innovation; Klitsie et al., 2019). Hence, CBM implementation would profit from obtaining funding for formal implementation and consortia focused on large-scale studies flanked by implementation-oriented work packages. A by-product of which would be collaboration and methodological alignment across labs/sites and countries. These efforts would ideally be supported by funding agencies whose strategic plans specify dissemination and implementation as priorities (e.g., the National Institute of Mental Health; NIMH). Relatedly, the CBM field should invest in cost-effectiveness studies as showing financial benefits of integration of CBM in clinical care is a crucial step towards uptake of CBM in clinical guidelines, institutions' mental health care policy, and health insurance packages, which are in turn conditional for sustainable funding of CBM application (e.g., De Mévergnies et al., 2023).

Platform selection/integration. To optimize the uptake of CBM in clinical practice it is critical that the programs (software) used in research are adapted such that they are user-friendly and easy to implement in busy treatment settings. CBM researchers should consider formal collaboration with stable (e/m-) MentalHealth providers (i.e., industry partners) to tackle long-term support issues. This will allow CBM to be sustainably implemented and disseminated, with the bonus of integrating CBM in a wider digital mental health provision. It is important to note that for researchers, working with industry can be challenging and getting innovation or valorisation experts involved is vital to success. Critically, we emphasize that these "roll-outs" - particularly direct-to-consumer roll-outs - will happen and are already happening, irrespective of research involvement. Digital mental health remains largely unregulated, and profit motivations may lead some companies to distribute sub-standard interventions. Having clinical researchers actively reach out to private partners and seek formal collaboration can help create a more evidence-based CBM treatment provision. Correspondingly, it may be valuable to consider during deployment not only strategies for reaching the target population (sensitivity), but perhaps also strategies for discouraging and redirecting consumers for whom the intervention is unlikely to be effective (specificity).

4. Concluding remarks

With the current paper, the ACBM community provides a foundation for targeted implementation efforts where interventions are ready for dissemination, highlights areas in need of further efficacy and effectiveness testing, and offers cautions regarding approaches that should not be disseminated at this time. We propose that it is time for CBM interventions with demonstrated efficacy - such as ApBM for alcohol use disorder and CBM-I for anxiety - to be "rolled out" to the targeted populations and settings. Although it is valuable to learn more about the mechanisms and efficacy of a given intervention, closing the research-to-practice gap must also be a priority. We must ensure that our extensive research yields evidence-based CBM interventions that actually reach the people who need them. We believe that, as a digitally native intervention, CBM has the potential for large reach and scale-up, especially in the context of collaboration with industry partners.

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Janna N. Vrijsen: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Conceptualization. **Ben Grafton:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Ernst H.W. Koster:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Jennifer Lau:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Charlotte E. Wittekind:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Yair Bar-Haim:** Writing – review & editing. **Eni S.**

[4] Efficacy denotes the performance of an intervention under ideal and controlled conditions, while effectiveness gauges its real-world impact and performance across a broader population and condition.

Becker: Writing – review & editing. **Melissa A. Brotman:** Writing – review & editing. **Jutta Joormann:** Writing – review & editing. **Amit Lazarov:** Writing – review & editing. **Colin MacLeod:** Writing – review & editing, Investigation, Conceptualization. **Victoria Manning:** Writing – review & editing. **Jeremy W. Pettit:** Writing – review & editing. **Mike Rinck:** Writing – review & editing, Investigation, Conceptualization. **Elske Salemink:** Writing – review & editing. **Marcella L. Woud:** Writing – review & editing. **Lauren S. Hallion:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Investigation, Conceptualization. **Reinout W. Wiers:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Conceptualization.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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