Cognitive Bias Modification Approaches to Anxiety

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Abstract

Clinical anxiety disorders and elevated levels of anxiety vulnerability are characterized by cognitive biases, and this processing selectivity has been implicated in theoretical accounts of these conditions. We review research that has sought to evaluate the causal contributions such biases make to anxiety dysfunction and to therapeutically alleviate anxiety using cognitive-bias modification (CBM) procedures. After considering the purpose and nature of CBM methodologies, we show that variants designed to modify selective attention (CBM-A) or interpretation (CBM-I) have proven capable of reducing anxiety vulnerability and ameliorating dysfunctional anxiety. In addition to supporting the causal role of cognitive bias in anxiety vulnerability and dysfunction and illuminating the mechanisms that underpin such bias, the findings suggest that CBM procedures may have therapeutic promise within clinical settings. We discuss key issues within this burgeoning field of research and suggest future directions CBM research should take to maximize its theoretical and applied value.

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INTRODUCTION

Scientific progress is characterized by a close association between advancement of understanding and increased ability to bring about change. Deeper understanding of any complex system results in a heightened ability to identify the changes to key variables needed to produce desired outcomes. Of equal importance, it is by changing such variables and observing

the consequences that understanding is deepened. Hence, the ability to directly manipulate component elements of a complex system is of crucial importance if we are to gain insight into its nature and effectively exploit the resulting applied benefits.

Cognitive models of anxiety vulnerability and dysfunction have proven highly influential across recent decades (cf. Brown & Barlow 1994, Clark & Beck 2010). These models share the premise that biased patterns of basic information processing, operating early within the cognitive system and at a low level that may be inaccessible to awareness, play a central causal role in vulnerability to experience unduly intense anxiety symptoms, though the specific nature of the proposed cognitive biases varies from theory to theory (cf. Mathews & MacLeod 2005). Despite the indirect support such accounts have received from confirmation that such processing biases are indeed characteristic of heightened anxiety vulnerability and anxiety pathology (cf. Ouimet et al. 2009), the ability of researchers to adequately test the crucial idea that cognitive biases causally influence clinically relevant symptoms has been handicapped by the lack of established procedures to directly manipulate these cognitive biases. This also has limited the ability of clinicians to deliver the potential therapeutic benefits such theoretical accounts predict should be gained from the direct modification of these biases for individuals experiencing problematic anxiety.

Hence, there has been considerable interest in recently developed techniques that have proven capable of directly modifying low-level cognitive biases implicated in such models of anxiety pathology (cf. Bar-Haim 2010, Hakamata et al. 2010, Hallion & Ruskio 2011, Hertel & Mathews 2011, Mathews 2011). The exponential growth of research employing these cognitive bias modification (CBM) procedures has been remarkable. Although the seminal studies were conducted around a decade ago, over 70% of the contemporary CBM literature is composed of publications that have appeared only within the past three years. We provide an overview of this rapidly developing new field of clinical research, focusing particularly on its contribution to the understanding and attenuation of dysfunctional anxiety. Although the great majority of CBM work published to date has focused on attentional bias and interpretive bias, the principles underlying the CBM approach can readily be extended to other types of cognitive biases also.

BACKGROUND TO COGNITIVE BIAS MODIFICATION RESEARCH

Cognitive Bias and Anxiety

Cognitive accounts of anxiety dysfunction attribute both heightened anxiety vulnerability and clinical anxiety to maladaptive patterns of selective information processing. They have been motivated by the observation that patients with anxiety disorders commonly report experiencing distinctly threatening thoughts of a type that plausibly could elicit, sustain, or intensify their anxiety symptoms (e.g., Ghahramanlou-Holloway et al. 2007). However, theoretical models developed to explain these idiosyncrasies in thought content causally attributed them to systematic biases in low-level cognitive mechanisms not readily available to introspective assessment. In particular, biases in attention and interpretation that operate to selectively favor the processing of emotionally negative information have commonly been implicated in these models of anxiety, and sometimes biases in memory function also have been thought to play a role (cf. Ouimet et al. 2009). Cognitive-experimental methodologies that directly assess selective information processing have confirmed the presence of such biases both in people suffering from anxiety disorders and in nonclinical individuals with an elevated dispositional vulnerability to experience anxiety symptoms.

Clinically anxious patients reliably display an attentional bias toward negative information, which is also sometimes shown by healthy individuals who reported elevated levels of trait anxiety (cf. Bar-Haim et al. 2007). This attentional bias has been assessed in a variety of

Anxiety vulnerability: a continuously distributed individual difference variable reflecting tendency to readily experience anxiety

Cognitive bias: systematic selectivity in information processing that operates to favor one type of information over another

Cognitive bias modification (CBM): direct manipulation of a target cognitive bias, by extended exposure to task contingencies that favor predetermined patterns of processing selectivity

Attentional bias: a commonly studied form of cognitive bias involving preferential attention to one particular type of information

Interpretive bias: a commonly studied form of cognitive bias involving the tendency to preferentially resolve ambiguity in one particular way

Anxiety dysfunction: problematic anxiety symptoms that are unwarranted by the situation and interfere with adaptive functioning

Anxiety disorder: a particular syndrome of dysfunctional anxiety symptoms matching diagnostic criteria for one of several clinically recognized categories of anxiety pathology

ways. Some techniques, such as the emotional Stroop task, require participants to ignore emotionally toned distracting information while performing a central task, and selective attention to emotionally negative distractors is inferred by measuring the degree to which their presence disproportionately disrupts central task performance (cf. Williams et al. 1996). Other approaches involve search tasks, where participants scan arrays of stimuli, and attentional bias is inferred from the relative speed with which they can locate targets of differing emotional tone (e.g., Olatunji et al. 2010). Perhaps the most widely used method of assessing anxiety-linked attentional bias has been the visual probe task, in which stimuli that differ in emotional tone are briefly exposed on a computer screen before a small visual probe appears in the locus where one or other emotional stimuli were exposed (e.g., Koster et al. 2006, MacLeod et al. 2007). Participants must quickly discriminate probe identity, and relative speeding to do so when probes appear in the locus of negative stimuli provides an index of selective attention to such information. Such assessment techniques have repeatedly demonstrated attentional bias to negative stimuli in both clinical and nonclinical manifestations of dysfunctional anxiety (cf. Cisler & Koster 2010). Attentional bias to disorder-relevant information has sometimes been observed in other conditions, such as depression (e.g., Baert et al. 2010).

Interpretive bias, reflecting selective imposition of negative meanings on ambiguity, also has proven characteristic of clinical and subclinical anxiety dysfunction (cf. Mathews 2011). A common assessment approach has been to examine the impact of initial ambiguous information on the processing of subsequent target information differentially related to alternative meanings of the preceding ambiguity. For example, participants have been exposed to narrative descriptions of ambiguous scenarios and required after each to make a simple judgment about a final target word, such as whether it is grammatically or lexically legitimate. An interpretive bias favoring negative resolutions of the initial ambiguity is revealed by a processing advantage for targets consistent with this particular meaning (Hirsch & Mathews 1997). Another technique used to assess anxiety-linked interpretive bias involves having participants read descriptions of ambiguous scenarios and then giving them a recognition memory test that presents disambiguated versions of these scenarios so that their interpretations of the initial ambiguity can be inferred from the subjective familiarity of the alternative disambiguations encountered in the memory test (Eysenck et al. 1991). Using such assessment procedures, it has been clearly demonstrated that participants with elevated anxiety vulnerability or suffering from clinical anxiety are disproportionately inclined to interpret ambiguity in a negative manner (cf. Richards 2004). Interpretive bias operating to selectively resolve ambiguity in a negative manner also is associated with depressive disposition (e.g., Ree et al. 2006).

Evidence of an anxiety-linked memory bias has been more mixed (cf. MacLeod & Mathews 2004). Such a bias has sometimes been observed both in clinical anxiety patients and in nonclinical participants with elevated trait anxiety (e.g., Ghassemzadeh & Baraheni et al. 2003), though it is a more robust characteristic of clinical and subclinical depression (cf. Mathews & MacLeod 2005). Anxiety vulnerability and dysfunction also is associated with certain patterns of appraisal bias that plausibly may contribute to anxious symptomatology. For example, the biased appraisal of anxiety symptoms themselves, resulting in their attribution to sinister causes and imbuing them with the capacity to cause harm, is the key characteristic of elevated anxiety sensitivity (Reiss et al. 1986), a disposition predictive of anxiety pathology (Taylor et al. 1992). Similarly, biased appraisal of intrusive negative thoughts, resulting in the assumption of personal responsibility for these mental events, is a characteristic of obsessive-compulsive disorder, which may contribute to the heightened capacity to elicit anxiety in individuals with this condition (Salkovskis & Forrester 2002).

The compelling evidence that dysfunctional anxiety is characterized by these patterns of selective information processing lends plausibility to theoretical accounts that implicate such cognitive bias in the etiology of anxiety disorders and in the origin of anxiety vulnerability. Nevertheless, these findings cannot serve to determine the causal status of cognitive bias in this observed association.

The Purpose of Cognitive Bias Modification Research

CBM research has not been motivated by a single purpose. Rather, the following three related objectives have been pursued through the development and application of CBM methodologies:

1. To determine the causal status of cognitive bias: Demonstrating an association between a particular cognitive bias and a heightened disposition to experience anxiety does not permit the conclusion that the bias causally contributes to this disposition. A powerful way of determining if one variable causally influences another is to test whether the direct manipulation of the first serves to alter the second. Hence, an early impetus for the development of CBM methodologies was to enable the direct manipulation of such biases to test the veracity of those theoretical models of anxiety that attribute causal status to them.
2. To evaluate the therapeutic potential of direct bias modification: Early CBM research demonstrating that CBM could temporarily alter anxiety vulnerability generated interest in the possibility that these methodologies may have practical application in the therapeutic attenuation of anxiety dysfunction. This has led to research designed to evaluate the capacity of CBM procedures to alleviate problematic anxiety symptoms and to ameliorate anxiety responses to stressful environments.
3. To illuminate the nature of cognitive bias mechanisms: Developing the capacity to manipulate a process brings with it the opportunity to learn about the mechanisms underpinning that process. Just as the development and refinement of conditioning techniques to modify behavior shed much light on the fundamental learning mechanisms that govern behavioral variability, so too has the development and evaluation of CBM techniques enabled researchers to illuminate the fundamental information-processing mechanisms that govern anxiety-linked patterns of cognitive bias.

CBT: cognitive behavior therapy

The pursuit of these three objectives has been closely intertwined. CBM work designed to advance understanding of causality has shaped therapeutic applications of CBM delivered to clinically anxious participants, while the outcomes of this latter work in turn have shed light on the causal contributions of selective information processing to anxiety disorders. Both lines of research have served to increase understanding of the mechanisms that underpin anxiety-linked cognitive bias.

The Nature of Cognitive Bias Modification Methodologies

The idea that dysfunctional patterns of thinking may contribute to anxiety pathology has driven the development of cognitive behavior therapy (CBT) for clinical anxiety disorders (cf. Clark & Beck 2010). Conventional CBT interventions typically aim to (*a*) provide patients with insight into the roles their thoughts play in the generation and maintenance of their anxiety symptoms, (*b*) assist them in identifying unhelpful thoughts that trigger such symptoms, and (*c*) encourage and enable them to challenge these thoughts in ways that reduce their credibility and attenuate their emotional influence. In contrast, CBM is not designed to alter the manner in which individuals respond to anxiogenic thoughts but rather to directly change the cognitive processes that give rise to such thinking. Koster and colleagues (2009) identify two key features of such CBM methodologies. First, each CBM procedure

CBM-A: cognitive bias modification targeting selective attention

is designed to directly alter one specific low-level bias in selective information processing, theoretically implicated in the generation of dysfunctional anxiety and usually assumed to operate prior to conscious thought. Second, CBM does not rely on insight, as the targeted biases need not be introspectively accessible. Rather, it seeks to modify the target bias through extended practice on a task configured to induce such change. In the majority of cases, this is a reconfigured variant of a cognitive-experimental task that previously has been employed to assess this specific cognitive bias and that has proven capable of distinguishing participants who differ in terms of anxiety vulnerability or dysfunction. The reconfiguration involves introducing a training contingency into the task, such that ease of task performance will be enhanced by acquisition of the intended bias change. Generally, participants are not informed of this training contingency, and they usually are unable to subsequently report it. Hence, as Beard (2011) observes, though completion of a CBM task may be volitional, neither the cognitive bias targeted by this procedure nor the process through which bias change is induced is assumed to be under volitional control.

The precise nature of the CBM depends upon the particular type of bias that it is intended to change. In the following sections, we separately review the development and application of CBM procedures designed to modify attentional and interpretive bias. We also consider how the CBM approach is being extended to target some other types of clinically relevant processing selectivity.

COGNITIVE BIAS MODIFICATION TARGETING ATTENTIONAL SELECTIVITY

Development of Attentional Bias Modification Techniques

Researchers began developing cognitive bias modification procedures to change attentional selectivity (CBM-A) around the mid-1990s (e.g., MacLeod 1995), and Mathews & MacLeod (2002) provide an early review of this work. The CBM-A approach that has been most frequently employed across recent years represents a training version of the attentional probe task previously used to assess anxiety-linked attentional bias (MacLeod et al. 1986). In the assessment version of this task, probes are presented equally often in the screen locations where either the negative or neutral member of a stimulus pair just appeared. However, in the bias modification version of the task, the probes always appear only in the locus of the negative stimuli (attend-negative training) or the neutral stimuli (avoid-negative training). Whether the emotional stimuli are words or images, Mathews & MacLeod (2002) report that extended exposure to these alternative training conditions serves to induce differential attentional responding to negative information. For example, in two studies using word stimuli, MacLeod and colleagues (2002) exposed participants to 576 trials of this CBM-A task in either of the training conditions. When attentional selectivity was subsequently measured using new word stimuli and the conventional assessment version of the probe task, participants given the alternative training conditions were found to differ in attentional bias. Those who had completed attend-negative training showed a relative speeding to probes in the locus of negative words, indicating attentional vigilance for negative stimuli. In contrast, participants who had completed avoid-negative training showed disproportionate slowing to probes in the locus of negative words, indicating attentional avoidance of such stimuli.

The majority of attentional bias modification studies to date have employed variants of this probe CBM-A approach, and its capacity to modify attentional selectivity is now well established (cf. Hakamata et al. 2010). However, other approaches also have been developed. For example, Dandeneau & Baldwin (2004) developed a visual search CBM-A procedure, designed to suppress attention to negative stimuli while developing attentional vigilance

for positive stimuli, that required participants to search for a single positive stimulus in a matrix otherwise comprising negative distractor stimuli. Compared to a control condition, this has been found to reduce attentional vigilance for negative stimuli as assessed using either the emotional Stroop task (Dandeneau & Baldwin 2004, Dandeneau et al. 2007) or the attentional probe task (Dandeneau & Baldwin 2009, Dandeneau et al. 2007).

Single-Session Applications of Attentional Bias Modification

As we have discussed, attentional bias to negative information is associated with heightened anxiety vulnerability. CBM-A techniques have been used within single-session laboratory studies to evaluate the hypothesis that such attentional selectivity causally contributes to this disposition by testing whether its modification affects readiness to experience anxiety symptoms. For example, after having successfully induced differential attentional response to negative information in two groups of mid-trait anxious participants using the probe CBM-A approach, MacLeod et al. (2002) exposed them to a stressful anagram task. The degree to which this stressor elicited anxiety depended on CBM-A condition. Relative to participants exposed to the attend-negative condition, those who received the avoid-negative condition displayed attenuated anxiety responses to the anagram stressor. Moreover, participants who developed the most pronounced attention avoidance of negative information in response to the CBM-A manipulation came to display greatest attenuation of emotional reactivity to the stressor. Eldar and colleagues (2008) obtained similar findings using a pictorial version of this probe CBM-A procedure in unselected 7- to 12-year-olds. Children exposed to the avoid-negative CBM-A condition subsequently showed less attention to negative information than did children exposed to the attend-negative condition. Most importantly, in response to a subsequent puzzle task stressor, the latter children reported a robust elevation of anxiety while the former children reported no significant elevation of anxiety. Independent raters confirmed that the children who received avoid-negative CBM-A also displayed fewer behavioral signs of anxiety during the problem task.

Modification of attentional bias using the visual search variant of CBM-A also has been found to influence emotional vulnerability. Dandeneau & Baldwin (2009) gave unselected participants from an adult education center either a single session of this CBM-A task, configured to induce attentional avoidance of frowning faces, or a control task with no attentional training contingency. The former condition served to reduce attentional bias to social rejection information, as revealed by a subsequent probe assessment procedure. It also served to attenuate the feelings of rejection later elicited by a simulated social interaction. This beneficial effect of the CBM-A training was especially evident for participants who initially scored low on measures of self-esteem. Findings of this type lend clear support to the hypothesis that biased attentional response to negative information can make a causal contribution to emotional vulnerability. They also suggest the clinically important possibility that people with an elevated disposition to experience dysfunctional symptoms may potentially benefit in practical ways from CBM procedures. Research examining the impact of CBM-A in participants chosen because they exhibit problematic anxiety symptoms has further supported the potential therapeutic value of CBM-A approaches while lending weight to the hypothesis that attentional bias causally contributes to anxiety dysfunction.

Amir et al. (2008) exposed participants who reported difficulty with public speaking to a single session of pictorial probe CBM-A, either in the avoid-negative condition or in a control condition containing no attentional training contingency. As intended, those in the former condition came to display greater attentional avoidance of negative information compared to participants in the control condition. Of most importance, they also reported lower levels of state anxiety and were judged by raters to

exhibit less behavioral evidence of anxiety when subsequently delivering a short speech. The impact of the CBM-A manipulation on both measures of anxiety was statistically mediated by its effect on attentional bias. Reduction of attentional bias to negative information also reduces negative thought intrusions in people who show an excessive tendency to worry. Hayes and colleagues (2010) assigned participants scoring above 56 on the Penn State Worry Questionnaire (Meyer et al. 1990) to either a control condition or to CBM-A configured to elicit attentional avoidance of negative verbal stimuli. In addition to inducing such change in attentional bias, this CBM-A also attenuated negative thought intrusions during a subsequent worry-induction procedure. Hirsch and colleagues (2011) contrasted the impact of two variants of CBM-A on negative thought intrusions during a subsequent worry-induction task. One variant was designed to inhibit attentional engagement with negative information by reducing the degree to which participants selectively moved attention toward negative information presented outside initial attentional focus. The other variant was designed to facilitate attentional disengagement from negative information by increasing the degree to which participants moved attention away from negative information presented within initial attentional focus. Hirsch et al. (2011) found that the former CBM-A procedure was more effective than the latter in attenuating subsequent negative thought intrusions. This led them to conclude that biased attentional engagement with negative information may make the greater causal contribution to this type of anxiety symptom.

Najmi & Amir (2010) have reported beneficial effects of CBM-A in people displaying subclinical obsessive-compulsive symptoms. When given a single session of verbal probe CBM-A in the avoid-negative training condition, these participants came to show reduced attention to contamination-related information compared to participants exposed to a control procedure with no training contingency. Furthermore, they subsequently demonstrated heightened ability to perform a behavioral approach task (BAT) involving exposure to feared contaminants. Their improved BAT performance was mediated by the CBM-A-induced change in attentional bias. In a recent extension of Eldar et al.'s (2008) study, Bar-Haim et al. (2011) investigated whether the benefits of CBM-A would extend to a sample of children selected on the basis of exhibiting chronically high anxiety levels on the Screen for Child Anxiety Related Emotional Disorders (Birmaher et al. 1999). These dispositionally anxious children did indeed show attenuated anxiety reactivity to a puzzle stressor following exposure to an avoid-negative CBM-A procedure.

Such findings indicate that the causal influence of attentional bias extends to dysfunctional manifestations of anxiety. Of course, it would be imprudent to conclude from this that attentional bias causally contributes to all forms of anxiety dysfunction. The consistent failure to influence particular types of anxiety symptoms through the use of CBM-A procedures also may be theoretically informative by serving to delineate those facets of anxiety that may owe little to the influence of attentional bias. Specific fear symptoms have proven particularly resistant to the influence of attentional bias modification. Single-session CBM-A procedures, successful in inducing attentional avoidance of spider-related information, do not attenuate self-report, behavioral, or physiological indices of spider fear in spider-fearful participants (Harris & Menzies 1998, Reese et al. 2010, Van Bockstaele et al. 2011). There is no doubt that selective attentional bias toward spider-related stimuli is a reliable feature of spider fear (e.g., Kindt & Brosschot 1997, Mogg & Bradley 2006). Nevertheless, the finding that its modification does not influence spider fear symptoms suggests that attentional bias does not causally contribute to this condition. It may be that other forms of selective information do play a functional role in specific fear, but Reese et al. (2010) suggest that attentional bias to negative information may contribute only to the pattern of distressing and repetitive

negative thinking that characterizes anxious rumination and worry, which is less evident in anxiety conditions involving specific fear.

As illustrated by studies of this type, the single-session application of CBM-A can powerfully contribute to the testing of hypotheses concerning the causal contributions made by attentional bias to differing facets of anxiety. The encouraging results obtained from single-session CBM-A studies have motivated investigators to examine the impact of more extended CBM delivery, and below we consider the contribution made by work that has delivered CBM across multiple sessions and has assessed its impact on anxiety experienced outside the laboratory setting.

Extended Applications of Attentional Bias Modification

The finding that transient modification of attentional bias impacts upon clinically relevant anxiety symptoms in a laboratory setting confirms that this bias can causally contribute to such symptomatology. It also suggests that CBM-A may be of potential therapeutic benefit in the alleviation of problematic anxiety. It does not, however, permit the conclusion that attentional bias makes a meaningful contribution to anxiety in the naturalistic setting. Nor does it mean that CBM-A can be delivered in a manner that produces meaningful change in naturally occurring anxiety symptoms within the real world. To address these important issues, researchers have sought to evaluate whether extended exposure to CBM-A can induce enduring attentional change that affects real-world experience. The findings generally support the hypotheses that attentional bias does causally contribute to anxiety symptomatology beyond the laboratory context and testify to the likely value of CBM-A in the treatment of anxiety dysfunction.

See and colleagues (2009) delivered an online version of the probe CBM-A procedure to Singaporean high school graduates on a daily basis for two weeks prior to their emigration to commence tertiary education overseas. Half received the avoid-negative CBM-A condition while half were exposed to a control condition with no training contingency. The former participants alone developed a robust attentional bias away from negative stimuli across the training period. State anxiety scores recorded immediately following the transition event were significantly attenuated in these participants relative to those in the control condition, and trait anxiety scores declined across the period of the study only for participants given the avoid-negative CBM-A training. The impact of the CBM-A manipulation on anxiety was mediated by its effect on attentional bias. Extended delivery of the visual search CBM-A also has been found to influence responses to a stressful work environment. Dandeneau et al. (2007) had telemarketers complete either the avoid-negative or control version of this CBM-A procedure every day for one week. Participants in the former condition alone reported increased self-esteem and reduced perceived stress. They also displayed lower cortisol release and cortisol reactivity than participants in the control group, confirming the attenuation of their stress response. Such findings indicate that attentional bias does have a causal role in shaping the emotional reactions to situational stress experienced in real-world settings.

Extended CBM-A can also influence symptoms associated with anxiety dysfunction. Hazen et al. (2009) delivered five daily sessions of probe CBM-A to a sample of extreme worriers, in either the avoid-negative or control condition. The former condition alone served to induce attentional avoidance of negative information and to significantly attenuate negative emotional symptoms. Pathological worry is the hallmark of generalized anxiety disorder (GAD), and Amir and colleagues (2009a) have demonstrated that the symptoms of this anxiety disorder also can be improved through the use of CBM-A. Patients with GAD were given eight sessions of probe CBM-A across a four-week period, again delivered either in the avoid-negative or control condition. Those in the former condition alone evidenced significant reduction of worry and anxiety, and

GAD: generalized anxiety disorder

GSD: generalized social anxiety disorder

CBM-I: cognitive bias modification targeting selective interpretation

such symptom improvement was mediated by the reduction of attention to negative information. Only 50% of the participants receiving avoid-negative CBM-A still met diagnostic criteria for GAD at the end of the four-week intervention, compared to 87% of the control group. Attentional bias modification also has been found to influence the symptoms of generalized social anxiety disorder (GSD). Using the same schedule employed by Amir et al. (2009a), Schmidt and colleagues (2009) exposed GSD patients to a variant of this probe CBM-A procedure that modified attentional response to faces displaying critical expressions. Unlike those in the control condition, participants in the avoid-negative condition showed significant reductions in anxiety and depression symptoms, maintained at four months. Only 38% of these participants continued to meet diagnostic criteria for GSD at the end of the CBM-A program compared to 89% of the control group. Similarly impressive findings have been reported by Amir et al. (2009b), who delivered this same CBM-A procedure to individuals with generalized social phobia. Unlike control participants, those who received avoid-negative training evidenced a significant reduction of clinical symptoms, fully maintained at four-month follow-up, and this symptom improvement was mediated by the CBM-A-induced change in attentional bias. Emotional dysfunction in children and youths also may be responsive to this four-week CBM-A program delivered in the avoid-negative condition. Rozenman et al. (2011) reported that 10- to 17-year-old participants suffering from separation anxiety disorder, social phobia, or GAD responded to this with clinically significant reductions of anxiety symptoms, and only 25% of these participants met diagnostic criteria after the CBM-A intervention.

Findings from the studies reviewed in this section highlight the capacity of CBM-A to produce clinically relevant symptom change in participants suffering from dysfunctional anxiety and give grounds for optimism concerning the future therapeutic potential of extended CBM-A procedures in the treatment of anxiety disorders. Of equal importance, these same findings provide compelling evidence that biased patterns of attentional selectivity do causally contribute to the clinical symptoms of anxiety pathology.

COGNITIVE BIAS MODIFICATION TARGETING INTERPRETIVE SELECTIVITY

Development of Interpretive Bias Modification Techniques

In cognitive bias modification procedures that target interpretive bias (CBM-I), each trial first presents ambiguous information, after which the participant must make a decision that should be facilitated by one or other interpretation of this ambiguity. Required decisions are structured such that these consistently benefit from one particular pattern of selective interpretation, in the expectation that participants will come to favor this interpretive style. In the first reported CBM-I procedure, Grey & Mathews (2000) presented participants first with a homograph that permitted a negative and a more positive interpretation, such as "growth," which can be interpreted negatively to mean a bodily lump caused by disease or more innocuously to mean a general increase in size or importance. The homograph was followed on every trial by a word fragment that participants had to quickly complete. Fragment completion always yielded a word related to a meaning of the initial homograph, which consequently could be a useful aid to such completion. In the CBM-I condition designed to induce negative interpretive bias (interpret-negative), the solution to the fragment was always a word related to the negative meaning of the homograph. Thus, in this condition the homograph "growth" could be followed by the fragment C-NC-R, which yields the completion CANCER. In the other CBM-I condition, designed to induce more positive interpretive bias (interpret-positive), the solution to the fragment was always a word related to the homograph's more positive meaning. For example, in this condition the

homograph "growth" could be followed by the fragment GR-AT-R, which yields the completion GREATER. Following up to 240 CBM-I trials, the induced pattern of interpretive selectivity was assessed by measuring relative latency to process target words related to either meaning of a preceding homograph. Across two studies, performance on these assessment trials confirmed that participants exposed to the interpret-positive CBM-I condition came to show more benign interpretations of ambiguity than did those exposed to the interpret-negative CBM-I condition. Subsequent studies have confirmed that this CBM-I procedure modifies the selective interpretation of ambiguity (e.g., Grey & Mathews 2009).

Mathews & Mackintosh (2000) created a CBM-I variant in which each trial begins with the textual description of an ambiguous situation, and participants must complete a final word fragment to provide a meaningful ending. In the interpret-negative CBM-I conditions, final fragments can yield only completions consistent with the negative interpretation of the preceding ambiguity, whereas in the interpret-positive condition, they can yield only completions consistent with the positive interpretation of this ambiguity. Following 100 or so trials of this CBM-I procedure, Mathews & Mackintosh assessed interpretations of new ambiguous scenarios, using Eysenck et al.'s (1991) recognition memory procedure. Across a series of five studies, participants' familiarity ratings for disambiguated versions of these test scenarios confirmed that they had acquired a pattern of interpretive bias consistent with the direction of CBM-I training. The capacity of this CBM-I approach to reliably modify interpretive bias has been confirmed in subsequent work (e.g., Salemink et al. 2009).

Single-Session Applications of Interpretive Bias Modification

Mathews & Mackintosh (2000) found that participants who completed a single session of their CBM-I task in the interpret-positive training condition subsequently reported lower state anxiety levels than those who completed the task in the interpret-negative condition. Subsequent research confirmed and extended this finding, showing that a session of such CBM-I delivered in the interpret-positive condition, rather than the interpret-negative condition, led to significant decline not only in state anxiety but in trait anxiety questionnaire scores also (Salemink et al. 2007a, 2009). Salemink et al. (2009) demonstrated that the effect exerted by the CBM-I procedure on trait anxiety was mediated by the induced change in interpretive bias. As these investigators conclude, this suggests that interpretative bias makes a causal contribution to anxiety vulnerability.

To exclude the possibility that CBM-I-induced change in questionnaire measures of trait anxiety might reflect only the biased interpretation of past emotional experience rather than genuine change in anxiety vulnerability, researchers have examined whether CBM-I can influence subsequently observed emotional reactivity. Salemink et al. (2007b) found no difference in the degree to which a later anagram stressor served to elevate anxiety in participants previously exposed to the alternative CBM-I conditions. However, it should be noted that this was the single study in which these investigators also failed to find an impact of CBM-I condition on their questionnaire measure of trait anxiety, rendering conclusions difficult. Salemink et al. (2007b) also raise the possibility that their anagram stressor may have involved insufficient ambiguity for differences in interpretive bias to influence anxiety responses. Consistent with this possibility, better evidence for the causal involvement of interpretive bias in anxiety vulnerability has been obtained using a stressor that more clearly invites alternative emotional interpretation. After delivering a single session of Grey & Mathews' (2000) CBM-I task to mid-trait anxious students, Wilson and colleagues (2006) exposed them to brief video clips of real-life emergency situations in which the victim of a near disaster was injured but ultimately rescued. Participants who had just completed a CBM-I session in the interpret-negative condition demonstrated a pronounced

elevation of both state anxiety and depression in response to these video clips, whereas the clips did not elevate either anxiety or depression for participants who had completed CBM-I in the interpret-positive condition. CBM-I procedures also have proven effective in modifying interpretive bias in children and youths (Lothmann et al. 2011). When Muris and colleagues exposed schoolchildren aged 8–13 to a single session of CBM-I in the interpret-positive condition, these children judged subsequently presented ambiguous scenarios to be less threatening than did children who instead had been exposed to the interpret-negative CBM-I condition (Muris et al. 2008, 2009).

The results of these studies, carried out using unselected participant samples, clearly support the idea that interpretive bias causally contributes to variation in anxiety vulnerability, underpinning differential tendencies to experience elevated anxiety in response to situations that can be interpreted in different ways. However, this need not mean that interpretive bias also is causally implicated in the types of anomalous experience associated with anxiety dysfunction. Support for such a conclusion would be strengthened by the demonstration that CBM-I can attenuate pre-existing symptoms of this type. Several investigators have reported such evidence. Murphy et al. (2007) selected participants with pre-existing high levels of social anxiety and exposed them to a single session of an auditory CBM-I procedure based on Mathews & Mackintosh's (2000) task. Compared to participants given a control condition with no training contingency, those given interpret-positive CBM-I training subsequently imposed less-negative interpretations on ambiguous test scenarios and expressed lower expectations of feeling anxious in future social situations. Steinman & Teachman (2010) selected participants who scored high on the Anxiety Sensitivity Index (Reiss et al. 1986), a well-established vulnerability marker for anxiety pathology (Taylor et al. 1992), and gave them a single session of Mathews & Mackintosh's CBM-I task in either the interpret-positive condition or a control condition. The former participants, unlike the latter, came to display more benign interpretations of ambiguity, reduced scores on the Anxiety Sensitivity Index, and a trend toward attenuated anxiety responses to a subsequently delivered interoceptive exposure challenge.

It is interesting to note that, in keeping with attentional bias modification, CBM-I has not yet been shown to influence spider fear, despite the fact that spider-fearful individuals do tend to interpret spider-related scenarios in a disproportionately negative manner (de Jong & Muris 2002). Teachman & Addison (2008) exposed spider-fearful participants to a single session of Mathews & Mackintosh's (2000) CBM-I procedure in alternative conditions respectively designed to increase either negative or positive interpretations of spider scenarios. Although this successfully induced a group difference in interpretive bias, CBM-I condition did not influence the behavioral avoidance or subjective distress elicited by subsequent exposure to a large spider. Although Teachman & Addison (2008) emphasize the need for further research, their results suggest that interpretive bias may not causally contribute to spider fear. Perhaps, as Reese et al. (2010) propose may be the case for attentional bias, selective interpretation instead drives patterns of distressing negative thinking more characteristic of worry than specific fear.

Certainly, the modification of interpretive bias does appear to influence the frequency of negative thought intrusions in worry-prone individuals. A sample of such worriers, selected on the basis of their high scores on the Penn State Worry Questionnaire, was given a single CBM-I session by Hirsch et al. (2009). Participants who received an interpret-positive CBM-I procedure reported fewer negative thought intrusions during a subsequent breathing focus task than did participants who received a control procedure. Given that the hallmark of GAD is an inflated tendency to worry, Hirsch et al.'s findings suggest that interpretive bias may contribute to the symptomatology of this anxiety disorder. Consistent with this possibility, Hayes et al. (2010) have confirmed that CBM-I can indeed reduce negative thought

intrusions in participants who meet diagnostic criteria for GAD. When performing a breathing focus task immediately after a single session of the same CBM-I used by Hirsch et al. (2009), GAD patients exposed to the interpret-positive condition reported significantly lower rates of negative thought intrusion than did those who received the control condition.

Thus, studies delivering single sessions of CBM-I within the laboratory have proven capable of illuminating the causal status of interpretive bias. The results generally support the hypothesis that the selective interpretation of ambiguity can contribute to heightened anxiety vulnerability and to clinically relevant patterns of anxiety symptoms. We now consider findings from studies that have employed more extensive CBM-I delivery and examined its impact outside the laboratory setting.

Extended Applications of Interpretive Bias Modification

Researchers have only recently begun to investigate whether CBM-I can induce enduring change in interpretive bias in ways that influence real-world emotional experience. This work has revealed that the interpretive change induced by even a single session of CBM-I is surprisingly robust. Salemink & van den Hout (2010) observed that differential interpretive bias, induced by Mathews & Mackintosh's (2000) CBM-I procedure, was not attenuated by a mood induction subsequently administered in the same experimental session. When Yiend et al. (2005) investigated the temporal persistence of differential interpretive bias induced by such CBM-I, they found it to remain evident even after a 24-hour interval, which was the longest delay considered in their series of experiments. Mackintosh et al. (2006) further demonstrated that persistence of CBM-I-induced interpretive bias across a 24-hour period was unaffected by changing the contexts of the CBM-I training session and the interpretive bias assessment session. Mackintosh et al. also were able to show that the induced group difference in interpretative bias observed 24 hours after a single session of CBM-I was accompanied by a corresponding group difference in emotional vulnerability at this later point in time, as revealed by participants' anxiety reactions to the video stressor developed by Wilson et al. (2006). Therefore, a single session of CBM-I can exert a fairly enduring impact on both interpretive bias and anxiety vulnerability.

Nevertheless, researchers using CBM-I to investigate whether selective interpretation causally contributes to anxiety experience in real-world settings generally have employed multiple sessions of CBM-I delivered across more extended periods of time. For example, to determine whether CBM-I could alter high trait anxious individuals' emotional symptoms in their natural environment, Mathews et al. (2007) had them complete four CBM-I sessions across a two-week period. When assessed one week later, participants who received interpret-positive training evidenced reduced negative interpretation of ambiguity and reported lowered trait anxiety scores compared to control participants. The finding that extended CBM-I can reduce trait anxiety in participants with a pre-existing high level of anxiety vulnerability has proven to be reliable. Salemink et al. (2009) selected high trait anxious participants who showed a negative interpretive bias and gave them eight consecutive daily sessions of Mathews & Mackintosh's (2000) CBM-I procedure. Those who received interpret-positive CBM-I subsequently evidenced more positive interpretive bias than did control participants. They also demonstrated a significant decrease in trait anxiety scores and a reduction of scores on the SCL-90 (Derogatis & Lazarus 1994), which assesses general psychopathology.

Salemink et al. (2009) found no CBM-I induced change on a measure of social anxiety, though social anxiety may not have been a prominent symptom in their participants, who were selected on the basis of elevated trait anxiety alone. When socially anxious participants have been given extended exposure to interpret-positive CBM-I training, this has been shown to attenuate their social anxiety symptoms. Beard & Amir (2008) exposed such

participants to eight sessions of CBM-I across a four-week period and assessed the impact of this intervention two or more days later. Participants who had completed the interpret-positive CBM-I came to display reduced negative interpretations of ambiguity, and reduced social anxiety symptoms on the SPS, compared to control participants. This reduction of social anxiety symptoms was mediated by the observed change in their interpretive bias. Vassilopoulos et al. (2009) delivered three sessions of the same CBM-I procedure to 10- to 11-year-old socially anxious children across a seven-day period. When assessed 3 to 4 days later, negative interpretations of ambiguity had significantly declined in the children exposed to the interpret-positive CBM-I relative to control participants. The former children alone also evidenced a significant decline in their scores on the Social Anxiety Scale for Children (La Greca & Stone 1993) and expressed a reduced expectancy of experiencing anxiety in an anticipated social situation. Again, the magnitude of the CBM-I-induced reduction in negative interpretive bias significantly predicted the size of the observed reduction in social anxiety symptoms.

In summary, therefore, the use of extended CBM-I has served to indicate that interpretive bias can make a causal contribution to dysfunctional anxiety symptoms, with the possible exception of specific fear. The findings lend support to cognitive models that implicate biased interpretation in the etiology of anxiety pathology, and they bode well for the possibility that extended CBM-I may be of future therapeutic value in the treatment of anxiety disorders.

COGNITIVE BIAS MODIFICATION TARGETING OTHER TYPES OF PROCESSING SELECTIVITY

To date, CBM research has mostly focused on selective attention and interpretation. However, the scope of CBM techniques is beginning to expand as clinical investigators seek ways of directly manipulating other forms of selectivity, with the dual objectives of testing models that causally implicate these specific types of cognitive bias and potentially alleviating clinical symptomatology through their modification. Although much of this work is still in its infancy, we briefly consider several of these other CBM approaches to illustrate their diversity and communicate the likely flavor of things to come.

Modification of Memory

As we noted above, the relationship between anxiety and memory bias is presently unclear. Selective memory retrieval, favoring negative information, has sometimes been observed in anxious participants (e.g., Ghassemzadeh et al. 2003). However, this is an inconsistent finding (MacLeod & Mathews 2004), and it is unknown whether this bias in memory makes a contribution to anxiety vulnerability or dysfunction. Hence, it would be of value to develop CBM procedures capable of directly manipulating selective memory for negative material in order to test whether the modification of such memory bias exerts an impact on anxiety. Anderson & Green (2001) demonstrated that when participants were repeatedly exposed to cues previously associated with target memories, while endeavoring not to think of these target memories, then this effort to not think of them can drive active forgetting of such targets. Joormann and colleagues have adapted and extended this approach to successfully induce forgetting of negative target information (Joormann et al. 2005, 2009). As yet, it is not known whether successful application of this memory modification procedure serves to attenuate dispositional anxiety or dysfunctional anxiety symptoms. However, this would be expected if such selective memory bias causally contributes to these facets of emotion, and so future CBM work on this topic will be theoretically illuminating while also yielding potential applied benefits.

Modification of Imagery

Negative mental imagery is a common feature of psychological dysfunction (Hackman &

Holmes 2004), which some theorists propose may make an especially strong contribution to emotional symptoms such as anxiety (Holmes & Mathews 2005). This has led investigators to compare the efficacy of CBM-I procedures designed to target either imagery-based processing or verbally based processing in order to test the resulting prediction that the former will be more potent in influencing such emotional experience. For example, Holmes et al. (2006) used a single-session auditory CBM-I procedure to increase positive resolutions of ambiguous scenarios but varied whether participants were instructed to form mental images or verbal representations of these scenarios. The imagery condition was more effective in inducing a benign interpretive bias, and only in this condition did the CBM-I procedure serve to attenuate state anxiety. Holmes and colleagues (2009) have replicated this finding while also showing that the imagery variant of CBM-I led to greater attenuation of negative emotional response to a subsequent mood induction than was evident using the verbal variant. These findings are consistent with the premise that imagery makes a particularly powerful functional contribution to emotional experience and suggest that the clinical benefits of CBM designed to attenuate dysfunctional anxiety may be optimized by the use of procedures that directly target negative mental imagery.

Modification of Appraisal

Interpretive bias influences how people resolve the meaning of intrinsically ambiguous information. However, even when information is not itself ambiguous, people still vary in terms of how they appraise it, drawing differing inferences about its importance and implications. Some dimensions of anxiety vulnerability, such as anxiety sensitivity and obsessionality, are characterized by distinctive biases in such appraisal processes, and theorists have implicated these idiosyncratic patterns of implicational thinking in the generation of associated anxiety symptoms (Reiss et al. 1986, Salkovskis & Forrester 2002). The premise that dysfunctional emotional experience reflects maladaptive appraisal processes has motivated clinical researchers to seek ways of directly modifying appraisal styles. In some cases, participants have been exposed to scenarios and explicitly directed to practice appraising them in a prespecified manner, and benefits of such directed appraisal practice have been reported (e.g., Schartau et al. 2009, Watkins et al. 2009). These procedures involve the intentional practice of an instructed style of thinking, as in traditional cognitive behavior therapy, although the use of preconstructed scenarios enables such practice to be delivered in an intensive and controlled manner. They differ from CBM methodologies in that the tasks themselves contain no intrinsic training contingencies designed to shape acquisition of the desired cognitive change.

However, Lang and colleagues (2009) have adapted the CBM approach to modify selective appraisal. Their study tested the hypothesis that appraising negative intrusive memories as signs of weakness and instability serves to increase their frequency. Lang et al. amended Mathews & Mackintosh's CBM procedure by presenting on each trial a sentence communicating a possible appraisal of a negative memory intrusion, the nature of which depended upon the identity of a word fragment, which participants were required to quickly complete. By manipulating these word fragments such that their completion was made easier by the consistent adoption of a particular appraisal style, Lang et al. (2009) created appraise-negative and appraise-positive versions of this CBM procedure. Thus, for example, participants could encounter a sentence that began "Having intrusive memories means that I am coping" and ended with the fragment "b-dly" (yielding the completion "badly") or "we-l" (yielding the completion "well"), in the appraise-negative and appraise-positive versions, respectively. Participants received a single session of this CBM procedure, in either condition, before being exposed to a distressing film. Across the subsequent seven days, those who had received appraise-positive CBM reported lower levels

of negative memory intrusion concerning the film than did those who had received the appraise-negative CBM. These findings support the hypothesis that the manner in which negative memory intrusions are appraised causally influences their frequency.

It seems likely that this CBM approach could be extended to modify patterns of appraisal theoretically implicated in anxiety dysfunction, such as the negative appraisal of anxiety symptoms that characterizes heightened anxiety sensitivity or the biased appraisal of intrusive negative thoughts that leads individuals with obsessive-compulsive disorder to assume undue responsibility for them. Extensions of appraisal bias modification could serve to test hypotheses concerning the causal contributions made by such styles of appraisal to these types of problematic anxiety while also potentially providing a means of therapeutically attenuating their severity.

COGNITIVE BIAS MODIFICATION AND COGNITIVE MECHANISMS

CBM research not only provides insight into the causal role played by different forms of processing selectivity in shaping anxiety vulnerability and dysfunction but also can extend knowledge of the mechanisms underpinning these cognitive biases. Developing the capacity to modify a cognitive process deepens understanding of mechanisms in two interrelated ways. First, it requires researchers to identify the mechanisms that underpin the observed change in the target process. Second, by observing the degree to which the modification of one particular cognitive process does, or does not, exert an impact on other cognitive processes, it permits researchers to fractionate the cognitive system into its component elements, distinguishing which types of bias plausibly result from selectivity in shared mechanisms and which instead appear to reflect selectivity in the operation of independent mechanisms. We here consider several topical questions pertinent to each of these issues.

Can CBM Findings Be Attributed to Demand Effects?

An elementary issue concerns whether CBM operates by producing genuine change in cognitive bias and symptomatology or whether observed findings might instead represent demand effects. We consider demand effect explanations implausible for at least six related reasons. First, the predictions that most CBM studies are designed to test are not self-evident. Differences between CBM conditions are usually subtle, involving contingencies that are neither communicated to participants nor relevant to the decisions they are instructed to make. Demand effect accounts require not only that these contingencies be apprehended but also that participants accurately infer their expected impacts on both cognition and pertinent symptomatology and feel motivated to simulate these anticipated consequences. Second, even if this were the case, simulating the observed cognitive changes often would be extraordinarily difficult, such as requiring participants to display speeding of around 30 ms in one assessment condition compared to another (e.g., Eldar et al. 2008, Grey & Mathews 2000). Third, evidence that CBM can influence the targeted cognitive processes is not restricted to performance on assessment tasks but is supported by neurocognitive measures. For example, exposure to differing CBM-A training conditions modulates activity in neurocognitive systems implicated in attentional control (Browning et al. 2009, Eldar & Bar-Haim 2010). Fourth, symptom change is often highly specific. For example, demand effects cannot readily accommodate the observation that participants commonly report no difference in mood state directly following CBM-A or CBM-I but instead show differences in emotional reactivity only to a subsequent stressor (MacLeod et al. 2002, Wilson et al. 2006). Fifth, CBM-induced symptom change is observed on psychophysiological indices that lie beyond intentional control (Dandeneau et al. 2007). Sixth, when participants have been required to report their expectancies, such

reports have consistently led researchers to reject the plausibility of demand effect explanations of their findings (Hayes et al. 2010, See et al. 2009). Of course, although these considerations mitigate against demand effect accounts of CBM-A and CBM-I findings, researchers must continue to guard against their potential influence by employing designs that obscure experimenter expectations, objectively assess induced cognitive change, and supplement self-report symptom indices wherever possible with behavioral and physiological measures.

Do CBM Effects Reflect Change in the Intended Cognitive Process?

The fact that CBM procedures induce genuine cognitive change need not mean that they directly modify the intended cognitive processes. Typically, alternative CBM conditions involve differential exposure to key categories of information. In most of the described examples, for instance, these conditions plausibly result in differing exposure to negative information. Might differential exposure be responsible for the observed effects, without the need to implicate CBM-induced changes in interpretive and attentional bias? We consider two possible variants of this account.

The first possibility is that exposure to discrepant emotional information may induce differential mood states, with change in processing selectivity reflecting the indirect consequence of such mood change. However, even when alternative CBM training conditions do not directly influence mood state, they still elicit differential selective interpretation and attention (Hoppit et al. 2010, Wilson et al. 2006). Also, mood change has been statistically excluded as the source of observed cognitive change (Amir et al. 2008, Hirsch et al. 2007), and the experimental induction of differential mood state does not mimic the impact of CBM (Standage et al. 2010). Cognitive change elicited by CBM is unaffected by mood-induction procedures (Salemink et al. 2010) and can remain evident long beyond the likely duration of transient mood states (Hazen et al. 2009, Mackintosh et al. 2006). Hence it is unlikely that the bias change elicited by CBM is mediated by the impact of CBM procedures on mood (Mathews 2011).

An alternative possibility is that CBM may semantically prime those categories of information that participants are exposed to in ways that influence performance on bias assessment tasks. Particularly with respect to CBM-I procedures, such priming effects could in principle emulate the intended cognitive change without this change actually occurring. Specifically, participants completing CBM-I procedures that repeatedly expose them to either positive or negative target information related to alternative meanings of prior ambiguity might become better at processing this class of target information as a consequence of semantic priming without this reflecting changed interpretation of ambiguity. However, CBM-I induced change in the relative processing speed of discrepantly valenced target information is observed only when this information is differentially related to preceding ambiguity (Grey & Mathews 2009, Hoppitt et al. 2010, Wilson et al. 2010) and shows far greater temporal endurance than semantic priming effects.

The cognitive change resulting from CBM most likely reflects transfer of practiced processing selectivity from the training task to new situations that invoke this same cognitive process (Hertel & Mathews 2011). Transfer of training depends upon there being a close match between the cognitive processes implicated in both the training and transfer task (Blaxton 1989). Therefore, as we discuss below in more detail, examining transfer of training effects following CBM may shed light on the degree to which overlapping processes contribute to differing manifestations of cognitive bias.

Is CBM Change Restricted to the Targeted Cognitive Bias?

There is abundant evidence that CBM training commonly transfers to new stimulus materials presented in assessment versions of the bias

modification task. Such transfer is reassuring, but unsurprising, as the same cognitive process clearly operates in both the training and transfer task. This is an example of what Hertel & Mathews (2011) refer to as "near transfer." They use the term "far transfer" when CBM training influences emotional reactions to unrelated stress tasks or clinical symptomatology. Far transfer effects reveal that the same cognitive process modified within the CBM training session operates within the assessment setting to influence the dependent measures of interest.

One way in which CBM transfer effects can be informative about component cognitive processes is when supposedly near transfer fails to occur. The implication is that, despite superficial similarities, the cognitive process modified in the training task must be independent of those operating in the test task. There are many examples of successful near transfer across different tasks intended to measure the same cognitive process (e.g., Dandeneau & Baldwin 2004, Grey & Mathews 2000, Wilson et al. 2006). However, there have also been interesting and potentially important failures of seemingly near transfer. For example, Salemink et al. (2010) found that the effects of CBM-I training transferred to a quite different task, implicitly revealing the interpretations imposed on ambiguity. However, it did not influence performance on assessment tasks that required participants to explicitly report their preferred interpretations of ambiguous scenarios. This suggests that the cognitive processes governing self-reported beliefs about interpretive style may be unrelated to the cognitive processes that govern the resolution of ambiguity. Future mapping of near transfer failures may permit delineation of the boundaries between apparently similar patterns of selectivity that reflect fundamentally different cognitive mechanisms.

Another way in which CBM transfer effects can illuminate the cognitive mechanisms is when unexpected far transfer occurs between tasks previously thought to reflect different cognitive processes. Recently observed far transfer effects of this nature suggest that boundaries traditionally imposed by theorists between attentional, interpretive, and memory bias may need to be reconsidered. For example, it recently has been shown that the effect of probe CBM-A training designed to directly modify attentional bias can transfer to influence interpretive bias also (White et al. 2011). Conversely, the effect of CBM-I training designed to directly influence interpretive bias can transfer to modify attentional bias also (Amir et al. 2010). The modification of interpretive bias using CBM-I also has been shown to transfer to measures of memory bias (Salemink et al. 2010, Tran et al. 2011).

So CBM transfer of training effects suggests that at least some facets of attentional, interpretive, and memory bias stem from shared selective processing mechanisms and that some tasks intended to assess a single bias instead appear to measure independent cognitive mechanisms. The more systematic study of such transfer effects should assist future researchers to categorize and fractionate the array of cognitive mechanisms that contribute to the diversity of processing biases associated with clinically relevant dimensions of individual differences. Hence, in addition to their capacity to test causal hypotheses concerning the cognitive basis of anxiety and to attenuate dysfunctional anxiety, CBM methodologies also equip investigators with powerful new tools capable of illuminating the nature of anxiety-linked patterns of processing selectivity.

FUTURE DIRECTIONS FOR COGNITIVE BIAS MODIFICATION RESEARCH

Despite its relatively short history, CBM research already has shed light on the contributions made by selective information processing mechanisms to anxiety vulnerability and dysfunction and has given rise to promising new methods of ameliorating problematic manifestations of anxiety. Nevertheless, as we discuss below, there is great scope for further progress to extend the reach of this work, to enhance the efficacy of CBM procedures,

and to refine therapeutic application of CBM procedures within clinical interventions.

Extending the Reach of CBM Research

In this review we have focused on anxiety, and to date the CBM approach has most commonly been employed to investigate the contributions of selective information processing to anxiety-related conditions. However, cognitive biases have been implicated in a great many other forms of psychological dysfunction, such as depression (Baert et al. 2010), addiction (Wiers et al. 2007), eating disorders (Williamson et al. 1999), chronic pain (Eccleston & Crombez 1999), aggression (Bond et al. 2004), insomnia (Ree et al. 2006), and even schizophrenia (Beck & Rector 2005). Broadening the application of CBM research to such conditions would serve to determine which particular biases functionally contribute to which aspects of psychological dysfunction while also potentially increasing the therapeutic scope of future CBM interventions. Such work already has commenced with promising early results. Researchers have reported finding that CBM procedures can influence depression (Wells & Beevers 2010), addictive consumption (Fadardi & Cox 2009), body dissatisfaction and eating restriction (Smith & Rieger 2009), and pain perception (McGowan et al. 2009). Of course, such extension of CBM is certain to present new challenges. For example, when Steel and colleagues (2010) endeavored to attenuate anxiety in people with schizophrenia using the CBM-I procedure that Holmes et al. (2006, 2009) employed to modify interpretive bias in nonpsychotic samples, the procedure failed to influence interpretive bias in their schizophrenic sample. Steel et al. (2010) suggest this may reflect the atypical patterns of imagery evidenced by these participants. Hence, existing CBM tasks may not provide an adequate arsenal to modify the biases encountered in all disorders. Instead, this is likely to require development of new CBM techniques tailored to ensure their capacity to alter target biases in participants suffering from particular clinical conditions.

Researchers also should expand the breadth of outcome measures used in CBM studies to move beyond the present heavy reliance on self-report (MacLeod et al. 2009a). Only a few investigators have yet included behavioral measures of anxiety when assessing symptom change (Amir et al. 2008, Najmi & Amir 2010), and fewer still have considered physiological indices of such change (Dandeneau et al. 2007, Van Bockstaele et al. 2011). Their lead should be followed in future CBM work. Extending the range of symptoms measured will reveal the contributions made by particular types of cognitive bias to alternative categories of symptoms. It also should be possible to illuminate the functional relationship between these differing facets of anxiety symptomatology using CBM designs that more carefully delineate, and track over time, the sequential consequences of CBM across this broader range of symptom measures.

Enhancing the Efficacy of Cognitive Bias Modification Procedures

The more effectively CBM procedures can change target cognitive biases the more valuable they will be; thus, future work must seek to optimize their capacity to alter processing selectivity. Researchers are beginning to capitalize on the Internet to increase the ease with which participants can be exposed to CBM procedures for extended periods of time (MacLeod et al. 2007, See et al. 2009), and more widespread adoption of this approach could enhance training efficacy. Enabling CBM to be delivered outside the laboratory also could enhance transfer of training in ways that increase the impact of CBM in real-world settings. Such transfer of training might benefit from the future use of mobile audio devices to deliver CBM in external settings where computer access is impractical. The viability of this approach is supported by the recent success of auditory CBM-I variants in reducing anxiety symptoms (Holmes et al. 2006, 2009), and Standage et al. (2009) report that auditory and visual versions of CBM-I

procedures are equally effective in altering cognitive bias.

We can also expect to see further refinements of CBM tasks themselves, designed to enhance their capacity to alter cognitive bias. In choosing which refinements to evaluate, researchers will be influenced by their assumptions concerning the mechanisms through which current CBM procedures bring about observed cognitive change. In turn, determining whether their chosen refinements succeed or fail will test the validity of such assumptions. For example, differing views concerning whether CBM procedures alter cognitive selectivity through implicit or explicit processes seem likely to influence the future development of these procedures. In most CBM studies, investigators have found participants unable to report the training contingency, consistent with the idea that this exerts an implicit influence of processing selectivity. However, there have been occasional exceptions, where CBM has been found to exert a stronger influence on those participants who report awareness of the training contingency (Field et al. 2007), suggesting that CBM-induced change may result from explicit insight into the training contingency. These competing conceptions generate differing expectations concerning whether explicitly informing participants of the training contingency will enhance or impair the efficacy of CBM. As noted by Beard (2011), early findings concerning the impact of such instructional manipulation have been inconclusive. Krebs et al. (2010) found that explicitly communicating the training contingency increased the impact of CBM-A on worry, whereas MacLeod et al. (2009b) have reported that it eliminates such emotional impact. Further research is needed to resolve this issue, and this future work should strengthen the power of CBM procedures while also testing the veracity of competing views concerning the involvement of implicit or explicit processes in CBM.

The practical value of CBM also will be increased by methodological developments that enhance the generalization and temporal stability of induced bias change. In the great majority of CBM studies, induced change in processing selectivity has generalized to new information not employed in the training itself. However, in a few CBM-A studies such generalization to new stimuli has not been observed (e.g., Field et al. 2007, 2009), possibly because of the restricted range of training stimuli employed. There is a need to identify how best to construct and employ training stimulus sets such that generalization to new materials is optimized. One promising approach that warrants formal evaluation has involved gradually expanding the stimulus training set across the course of the CBM procedure such that the need to generalize past learning to new stimuli becomes an integral feature of the training experience (See et al. 2009). Generalization of CBM training to new contexts is likely to be facilitated by delivering such training across multiple contexts. However, even generalized change in dysfunctional cognitive bias will produce lasting benefits only if changes in bias endure across time. Hence, identifying reliable methods of maximizing stability of CBM training effects represents another important objective for researchers. The literature on massed versus spaced learning (Cepeda et al. 2006) suggests that the retention of CBM training effects may be enhanced by increasing the temporal separation of CBM training sessions (Hertel & Mathews 2011, See et al. 2009). Infrequent booster sessions, briefly re-exposing participants to the original CBM procedure, also may help to preserve CBM-induced changes in processing selectivity (MacLeod et al. 2009a). Experimentation designed to increase the magnitude, generalization, and stability of induced cognitive change will amplify the future value of CBM procedures.

Refining the Therapeutic Application of CBM in Clinical Contexts

Small-scale randomized controlled trials have supported the therapeutic value of both CBM-A and CBM-I in the treatment of GAD and

social anxiety disorders (e.g., Amir et al. 2009a,b; Schmidt et al. 2009; Vassilopoulos et al. 2009). However, we concur with Beard (2011) that the time is now right for large-scale formal field trials evaluating the clinical efficacy of CBM interventions across the spectrum of anxiety disorders. Such trials should not only compare the therapeutic efficacy of CBM against that of established interventions, including CBT and pharmacological approaches, but should also evaluate whether CBM can be profitably combined with these other approaches in anxiety management treatment packages. MacLeod et al. (2009a) suggest that therapeutic synergy could result from delivering CBM in conjunction with conventional CBT if the former serves to alter low-level patterns of processing selectivity underpinning threatening thinking and the latter to challenge the veracity of these negative thoughts. Likewise, CBM may augment self-delivered exposure treatments by altering selective cognition in ways that increase the frequency and duration of therapeutic exposure. On the basis of the observation that selective serotonin reuptake inhibitors elicit cognitive change of a type similar to that produced by CBM, Browning et al. (2010) predict that concurrent delivery of both interventions may prove more efficacious than either alone. A closely related issue concerns whether clinical benefits could be optimized by combining different variants of CBM. Given the evidence that psychological dysfunction often is characterized by the simultaneous operation of both attentional and interpretive bias, the simultaneous delivery of CBM-A and CBM-I could produce greater symptom improvement than their individual administration. Brosan and colleagues (2011) have confirmed the capacity of combined CBM-A and CBM-I to reduce symptom severity in clinically anxious outpatients but did not compare the therapeutic impact of their combined and individual delivery.

Tailored treatments deliver customized collections of therapeutic elements chosen to match the specific needs of individual patients. There is scope for tailoring CBM interventions to target the specific bias profiles shown by individual recipients. As yet it is not known whether CBM-A most effectively modifies anxiety symptoms in those who already display dysfunctional attentional bias while CBM-I does so most effectively for those who already display dysfunctional interpretive bias. However, it has been shown that people differ systematically in readiness to change their patterns of selective processing in response to CBM contingencies (Clarke et al. 2008). Therefore, future development of individualized assessment techniques to appraise the profile and malleability of target cognitive biases may assist in identifying the individuals whose anxiety dysfunction is most likely to benefit from particular CBM interventions.

Ultimately, to fully exploit the therapeutic potential of CBM techniques in the treatment of anxiety dysfunction, the techniques will need to be incorporated into packages that are acceptable to the end-user. In a recent study investigating clinically anxious patients' satisfaction with multisession CBM-A and CBM-I interventions delivered in a primary health care setting, Beard et al. (2010) obtained reassurance that the procedures were generally rated as acceptable. Nevertheless, recipients expressed a need to better understand how the procedures were supposed to help tackle their symptoms. Hence, future clinical investigators must successfully confront the challenge of identifying and communicating a clear rationale to patients that lends credibility to CBM interventions procedures without diminishing their therapeutic efficacy.

CLOSING COMMENTS

The existence of a robust association between selective information processing and anxiety has been firmly established for three decades. Across this same period of time, researchers have worked diligently to better understand the nature of this association and, in particular, to determine how biased cognition may

contribute to both anxiety vulnerability and to the types of clinical dysfunction observed in the anxiety disorders. The advent of cognitive-experimental techniques that have proven capable of directly modifying anxiety-linked cognitive biases represents a highly significant juncture in this research journey, and the recent adoption of these CBM approaches has brought the field to an exciting new threshold, which future clinical researchers may come to view as an important watershed. As we have shown in this review, CBM methodologies have now proven their ability to increase scientific understanding by revealing the causal contributions made by specific types of cognitive bias to anxiety symptomatology and to elicit desirable change by attenuating the severity of anxiety symptoms. Their dual capacity to advance understanding and to increase our ability to bring about change seems likely to assure such methodologies of a central role in theoretical and applied aspects of future clinical research.

Of course, it must be borne in mind that CBM research is still in its infancy. The present techniques are limited in scope and are unlikely to represent the most effective methods of modifying the cognitive biases they target. As these existing CBM procedures are refined and strengthened, and as new CBM techniques are developed to extend and augment those presently available, so the influence of this research approach is likely to steadily increase. CBM research findings already justify the conclusion that CBM methodologies represent powerful and valuable scientific tools. We would caution against the premature conclusion that CBM represents an effective stand-alone treatment for clinical anxiety disorders, as clinical field trials of appropriate scale have yet to be carried out. Almost certainly, such clinical conditions are multiply determined, making it unlikely that any one therapeutic approach will prove to be the proverbial magic bullet. Nevertheless, on the basis of the evidence to date, it seems highly probable that CBM approaches will prove to be therapeutically useful components of future treatment packages designed to alleviate psychological disorders that include, but probably will not be restricted to, clinical anxiety.

SUMMARY POINTS

1. The development of cognitive bias modification procedures in anxiety has been motivated by the three objectives of (*a*) determining whether cognitive biases causally contribute to anxiety vulnerability and dysfunction, (*b*) evaluating the capacity of bias modification procedures to contribute in a therapeutically useful way to the attenuation of anxiety, and (*c*) illuminating the nature of the mechanisms that underpin anxiety-linked cognitive bias.
2. Existing CBM methodologies have proven capable of directly modifying both selective attention to emotional information and selective interpretation of emotional ambiguity. The principles underlying these successful CBM approaches for manipulating selective attention and interpretation are being extended to develop new CBM variants designed to tackle other forms of cognitive bias, such as memory bias and appraisal bias.
3. Studies delivering single sessions of CBM within experimental settings have demonstrated that the modification of attentional and interpretive bias can influence anxiety responses to laboratory stressors both in unselected participants and in those selected on the basis of experiencing dysfunctional anxiety symptoms. This supports the hypothesis that these cognitive biases can causally contribute to anxiety vulnerability and dysfunction.

4. Studies delivering multiple sessions of CBM across more extended periods have demonstrated modification of attentional and interpretive bias that persists across time and leads to attenuation of anxiety responses to naturalistic stressors and to amelioration of clinical symptoms in individuals with generalized anxiety disorder, generalized social anxiety disorder, and generalized social phobia. This supports the potential therapeutic value of CBM in real-world settings.
5. By systematically investigating the transfer of CBM-induced change in targeted cognitive bias to assessment tasks that measure supposedly similar or distinct manifestations of processing selectivity, researchers are using CBM methodologies to categorize and fractionate the cognitive operations that underpin the spectrum of processing biases associated with anxiety vulnerability and dysfunction.
6. Though the mechanisms through which CBM procedures give rise to changes in cognitive bias are not yet fully understood, this cognitive change and its attendant emotional consequences do appear genuine, as the findings are resistant to alternative explanation, such as demand-based accounts.
7. Future research should seek to extend the reach of CBM approaches to the investigation and attenuation of other types of psychological symptoms known to be associated with biased patterns of information processing and to increase the power of CBM procedures to elicit robust cognitive change that generalizes to new situations and endures across time.
8. On the basis of the promise they have shown, the time is right for large-scale field trials designed to formally evaluate the capacity of CBM procedures to contribute to the treatment of different anxiety disorders within clinical settings. Such trials could profitably investigate how CBT can best be combined with existing therapeutic procedures to optimize clinical outcomes.

FUTURE ISSUES

1. Cognitive bias modification research to date has focused mostly on the capacity of CBM to influence anxiety-related conditions. Future work should continue extending the reach of the CBM approach to illuminate the causal contributions of information-processing selectivity to other clinically relevant conditions characterized by cognitive bias, such as depression, addiction, eating disorders, chronic pain, and aggression. In addition to advancing understanding of the role played by cognitive bias in these types of dysfunctions, CBM may also prove capable of contributing to their alleviation.
2. Although there have been important exceptions, most CBM studies have relied heavily on self-report measures of subjective experience when evaluating the impact of induced bias change. It will be important to broaden symptom measures to more routinely include behavioral and physiological indices. Not only will this increase confidence in the veracity of CBM-elicited symptom change, but it also may enable CBM investigators to test hypotheses concerning functional relationships between these differing categories of symptoms.

3. To increase the magnitude of the cognitive change elicited by CBM procedures, future researchers should systematically evaluate the relative efficacy of CBM variants that differ in the degree to which they exploit the change mechanisms theorists propose to be implicated in CBM. Among other possibilities, it will be important to determine how variations in the types of verbal instruction given to participants completing CBM procedures influence their capacity to alter selective information processing.
4. Future researchers should identify the methods of CBM delivery that maximize the generalization of induced changes in cognitive bias. It seems likely that maximizing generalization of bias change to new stimuli will require that the use of large stimulus sets in CBM training procedures, maximizing generalization of bias change to new assessment tasks, will be assisted by the use of multiple CBM training tasks, and maximizing generalization of bias change to new contexts will benefit from delivering the CBM training in diverse contexts.
5. The practical benefits of CBM will be greatest when the induced bias change endures across time. Further research is needed to identify the methodological procedures that yield the most stable changes in cognitive bias. The potential benefits of employing spaced learning procedures to extend retention of training should be systematically evaluated, and investigators also should examine how the use of infrequent top-up sessions can best contribute to the maintenance of initial bias change.
6. There is a pressing need for large-scale field trials employing formal protocols to evaluate the clinical efficacy of CBM in the treatment of the anxiety disorders and other forms of psychological dysfunction characterized by patterns of processing selectivity amenable to alteration using available CBM procedures.
7. Treatment trials should not only compare the efficacy of CBM against other established interventions for anxiety, including CBT and pharmacological approaches, but should also investigate whether the inclusion of CBM can augment the efficacy of these existing approaches. It is likely that CBM will make its most valuable contribution through its inclusion in multimodal treatment packages, and understanding how best to capitalize on the potential synergies between CBM and other therapeutic elements will ensure the optimal structuring of these packages.
8. It will be necessary to develop a framework for CBM delivery that end-users, including patients and therapists, find acceptable within the clinical settings. Although the efficacy of CBM may not rely on participant insight, the commitment to persevere with CBM procedures will depend upon recipients' appraising such techniques as potentially valuable. Hence, clinical researchers must identify the rationale that can be communicated to recipients and that serves most effectively to sustain their motivation to engage with CBM procedures, without compromising therapeutic efficacy.

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