



## Anxiety and attention to threat: Cognitive mechanisms and treatment with attention bias modification



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### ARTICLE INFO

#### Article history:

Received 10 December 2015

Received in revised form

23 July 2016

Accepted 1 August 2016

Available online 7 August 2016

#### Keywords:

Anxiety

Attention

Threat

Attention bias modification

Cognitive control

### ABSTRACT

Anxiety disorders are common and difficult to treat. Some cognitive models of anxiety propose that attention bias to threat causes and maintains anxiety. This view led to the development of a computer-delivered treatment: attention bias modification (ABM) which predominantly trains attention avoidance of threat. However, meta-analyses indicate disappointing effectiveness of ABM-threat-avoidance training in reducing anxiety. This article considers how ABM may be improved, based on a review of key ideas from models of anxiety, attention and cognitive control. These are combined into an integrative framework of cognitive functions which support automatic threat evaluation/detection and goal-directed thought and action, which reciprocally influence each other. It considers roles of bottom-up and top-down processes involved in threat-evaluation, orienting and inhibitory control in different manifestations of attention bias (initial orienting, attention maintenance, threat avoidance, threat-distractor interference) and different ABM methods (e.g., ABM-threat-avoidance, ABM-positive-search). The framework has implications for computer-delivered treatments for anxiety. ABM methods which encourage active goal-focused attention-search for positive/nonthreat information and flexible cognitive control across multiple processes (particularly inhibitory control, which supports a positive goal-engagement mode over processing of minor threat cues) may prove more effective in reducing anxiety than ABM-threat-avoidance training which targets a specific bias in spatial orienting to threat.

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Clinical anxiety is a common debilitating problem which is difficult to treat. Over a quarter of the population suffers from an anxiety disorder during their lifetime (Kessler et al., 2005). While medication and cognitive behaviour therapy (CBT) are effective for anxiety disorders (Bandelow et al., 2015; Olatunji, Cisler, & Deacon, 2010), these treatments have limitations, such as drug side-effects and drug dependence, and modest efficacy as only about half of anxiety sufferers respond successfully to CBT (Hofmann, Asnaani, Vonk, Sawyer, & Fang, 2012). Thus, there is a need to develop effective treatments for anxiety which can be delivered cheaply and safely to large numbers of anxious adults and children.

One such potential intervention is *attention bias modification* (ABM), a computer-delivered treatment for anxiety that emerged from research in experimental psychopathology (MacLeod & Mathews, 2012; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). The goal of ABM is to reduce anxiety by reducing *attention bias* (AB) towards threat, which refers to the preferential

tendency to allocate attention to threat-related information rather than nonthreat information. Despite initial promise, ABM has limited effectiveness in reducing anxiety (Cristea, Kok, & Cuijpers, 2015; Cristea, Mogoase, David, & Cuijpers, 2015; Heeren, Mogoase, Philippot, & McNally, 2015; Koster & Bernstein, 2015; Mogoase, David, & Koster, 2014; Van Bockstaele et al., 2014). To improve ABM, it is important to examine the cognitive mechanisms underlying AB in anxiety (Koster & Bernstein, 2015).

This article has seven main sections. First, it describes common methods of assessing and modifying AB, and considers the effectiveness of ABM in treating anxiety. Second, it outlines theoretical views of the relationship between anxiety and AB. Third, it looks at models of attention and cognitive control relevant to cognitive models of anxiety and AB. Fourth, it describes an integrative framework of cognitive mechanisms involved in AB and anxiety, which builds on ideas from these models, and considers how AB may be influenced by these mechanisms and related variables (e.g. individual-difference and task-related factors). Fifth, it considers how this framework may guide research into ABM. The sixth section briefly mentions other issues relevant to the framework. The final section provides summary and concluding comments (See

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Appendix for detailed list of contents.).

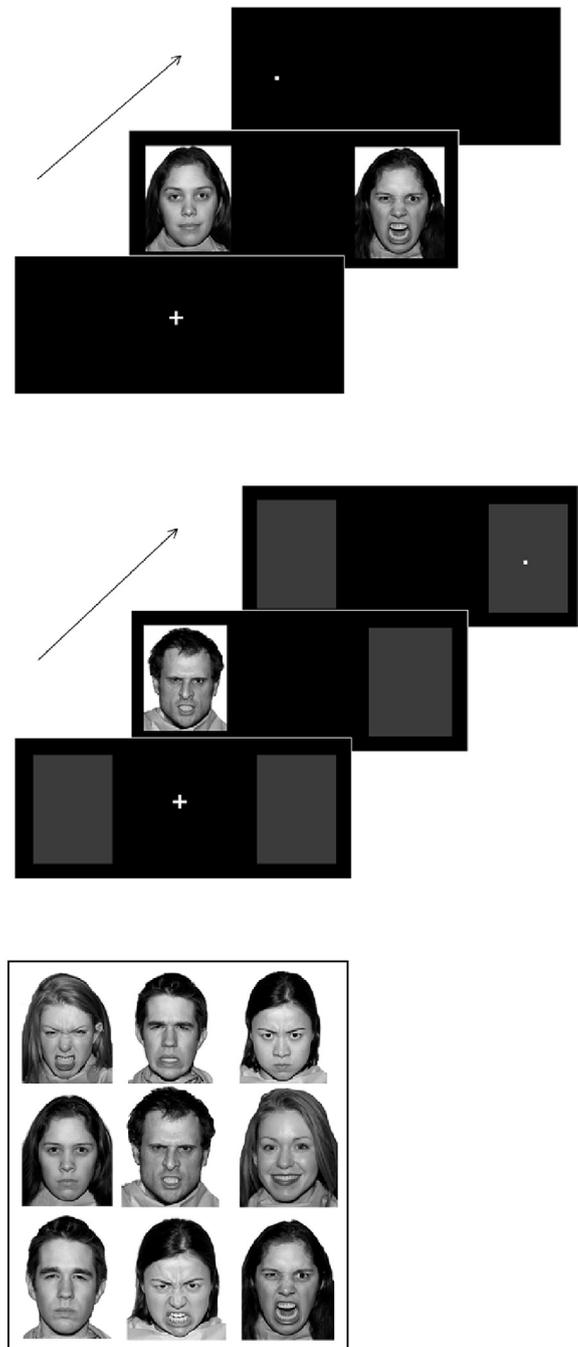
The primary focus of this article is on conceptual issues which relate to the cognitive mechanisms underlying AB and their implications for research into anxiety-related AB and ABM. Thus, it is beyond its scope to provide a detailed review of empirical findings of AB and other cognitive biases in anxiety (for reviews, see Armstrong & Olatunji, 2012; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Cisler, Bacon, & Williams, 2009; Cisler & Koster, 2010; Mathews, & MacLeod, 2005; Van Bockstaele et al., 2014; Weierich, Treat, & Hollingworth, 2008), or the neural bases of threat processing and anxiety (for reviews see Bishop, 2007; Kim et al., 2011; Lewis, 2005; Millan, 2003; Okon-Singer, Hendler, Pessoa, & Shackman, 2015; Pessoa & Adolphs, 2010; Pine, 2007). This article complements recent reviews of AB in anxiety (e.g., Cisler & Koster, 2010; Van Bockstaele et al., 2014) and considers further the roles of bottom-up and top-down processes involved in threat-evaluation, spatial orienting and inhibitory control in different manifestations of AB (initial orienting to threat, maintaining attention on threat, threat avoidance, threat-distractor interference) and in different types of ABM training. Before doing so, the main methods used to assess and modify AB are briefly outlined to facilitate evaluation of ABM.

## 1. AB and ABM: experimental methods and effects of ABM on anxiety

### 1.1. Methods used in assessing AB

The *visual-probe task* is widely-used to assess AB in spatial orienting to threat cues, such as threat words and pictures (MacLeod, Mathews, & Tata, 1986; Mogg & Bradley, 1999). A typical trial presents a central fixation cross, followed by a threat and nonthreat cue (e.g., angry and neutral face) briefly displayed together (see Fig. 1, upper panel). One of the cues is replaced by a probe (e.g., small dot, letter or arrow). The threat cues and probes appear randomly on either side of the screen with equal probability. Participants respond as quickly as possible to the probe with a button-press response (e.g., to indicate its location, or identify the probe type). An AB for threat is inferred from response times (RTs) to probes. If an individual has a bias to direct attention to the spatial location of threat (often called vigilance), this should be reflected by faster RTs to probes that appear in the same location as threat cues (*threat-congruent* trials) compared with RTs to probes that appear in the same location as nonthreat cues (*threat-incongruent* trials). Conversely, if an individual has a bias to direct attention away from threat (avoidance), this should be reflected by slower RTs to probes replacing threat than nonthreat cues. AB scores are the difference in RTs between threat-incongruent and threat-congruent trials (threat-incongruent minus threat-congruent); positive values reflect AB towards threat (vigilance), negative values reflect AB away from threat (avoidance), scores not significantly different from zero reflect no bias. The task provides a snapshot of AB which depends on the exposure duration of the cue-pair; this is commonly 500 ms, but may vary from very brief masked displays (e.g., 14 ms) to longer durations (e.g., 2000 ms) to examine the time-course of ABs, discussed later (Section 4.4.2).

Another common method of assessing AB is the *modified Stroop task*. It typically presents threat and nonthreat words in different colours and requires individuals to name the colour of each word as quickly as possible and ignore the word content (Mathews & MacLeod, 1985; Williams, Mathews, & MacLeod, 1996). The task is also used with images such as angry faces (e.g., Putman, Hermans, & van Honk, 2004; Reinholdt-Dunne, Mogg, & Bradley, 2009). Slower colour-naming of threat than nonthreat stimuli provides an



**Fig. 1.** **Upper panel.** Example of threat-incongruent trial on visual-probe task (probe in opposite location to that just occupied by threat cue). **Middle panel.** Example of invalid-threat cue trial on emotional spatial-cueing task (probe in opposite location to that just occupied by threat cue). **Lower panel.** Example of visual-search task trial showing a positive target (happy face) among threat distractors (angry faces). Faces are from the NIMSTIM set (Tottenham et al., 2009); not to scale.

index of AB to threat. Unlike the visual-probe task, it does not assess AB in direction of spatial orienting. Several mechanisms may contribute to the interference effect of task-irrelevant threat on performance, including automatic preferential allocation of attention resources to threat rather than task-related information, and automatic inhibition of ongoing cognitive and behavioural activity triggered by a bottom-up threat-detection mechanism; and cognitive effort involved in top-down attentional inhibition of threat distractors (Algom, Chajut, & Lev, 2004; De Ruiter &

Brosschot, 1994; Williams et al., 1996). A meta-analysis of 172 studies with over 2000 participants (mainly using visual-probe and modified Stroop tasks) concluded that anxiety is associated with an AB favouring threat information (Bar-Haim et al., 2007), although a recent review, which considers subsequent research, suggests that the relationship between anxiety and AB is less consistent than indicated by this meta-analysis (Van Bockstaele et al., 2014).

Other less frequently used methods for assessing AB include the *emotional spatial-cueing task* (Fox, Russo, Bowles, & Dutton, 2001) and *visual-search task* (Öhman, Lundqvist, & Esteves, 2001). The emotional spatial-cueing task was designed to assess biases in shifting and disengagement of attention (Fox et al., 2001). A typical trial displays a central fixation cross, followed a single cue, which is either a threat or nonthreat cue (e.g., angry or neutral face; see Fig. 1, middle panel). The cue is briefly displayed (e.g., 100 or 250 ms, Fox et al., 2001) on either the left or right side of the screen. After it disappears, a probe appears in either the same location (*valid-cue* trial) or opposite location (*invalid-cue* trial). Participants respond as quickly as possible to the probe. The premise of the task is that if an individual has a bias to shift attention towards threat they should show faster RTs to probes on valid-threat cue trials relative to valid-neutral cue trials. If they have difficulty disengaging attention from the spatial location of threat, they should show slower RTs to probes following invalid-threat cues, relative to RTs to probes following invalid-neutral cues.

The visual-search task presents stimulus arrays consisting of a target and distractors from different emotional categories (e.g., positive or neutral target among threat distractors; Fig. 1, lower panel). AB for threat is reflected by faster detection of threat targets among nonthreat distractors than vice versa; or more specifically by faster detection of threat (than nonthreat) targets embedded among nonthreat distractors; and from slower detection of nonthreat targets amongst threat (than nonthreat) distractors (Cisler & Koster, 2010; Öhman et al., 2001).

The above tasks provide RT-based measures of ABs. These have been complemented by studies of eye-movements and neural activity (e.g., ERP, fMRI) measured concurrently on AB tasks such as visual-probe and visual-search (e.g., Bradley, Mogg, & Millar, 2000; Britton et al., 2011; Holmes, Mogg, de Fockert, Nielsen & Bradley, 2014; Monk et al., 2008). (For reviews of AB assessment methods, see Van Bockstaele et al., 2014; Weierich et al., 2008).

### 1.2. Methods used in ABM training

ABM is based on the assumption that the AB towards threat plays a causal role in the etiology and maintenance of anxiety (MacLeod et al., 2002; MacLeod & Mathews, 2012; Van Bockstaele et al., 2014). According to some cognitive models of anxiety (Williams, Watts, MacLeod, & Mathews, 1988, 1997), individuals who have an enduring bias to automatically direct attention towards threat are prone to develop and experience chronic anxiety; whereas those with reduced susceptibility to anxiety (low trait anxiety) have the opposite bias, i.e., to avoid attending to threat. Thus, treatments which remove AB to threat and encourage threat avoidance may be effective in reducing anxiety (MacLeod & Clarke, 2015; MacLeod & Mathews, 2012). This idea underpins the most widely-used version of ABM which employs a modified version of the visual-probe task to train attention avoidance of threat cues (*ABM-threat-avoidance training*). In this task, the probe never replaces the threat cue and, instead, always replaces the nonthreat cue to encourage individuals to direct attention away from the spatial location of threat (MacLeod et al., 2002; see Fig. 1, upper panel for an example of such a trial). ABM-threat-avoidance training typically involves hundreds of training trials, following the assumption that the AB towards threat is automatic and habit-

driven. Verbal instructions to direct attention away from threat are usually not included in ABM-threat-avoidance training (MacLeod & Clarke, 2015; MacLeod et al., 2002), which seeks to induce automatic threat avoidance primarily by habit change via repeated behavioural practice, rather than by engaging intentional, effortful control strategies.

Another less common ABM method uses a modified version of the emotional spatial-cueing task (Fox et al., 2001). In this version, the probe never appears in the location where the threat cue has just appeared, in order to encourage attention to be directed away from the spatial location of threat (Bar-Haim, Morag, & Glickman, 2011; see Fig. 1, middle panel). Hence, this task is a variant of ABM-threat-avoidance training.

A limitation of ABM-threat-avoidance training is that not all anxious individuals show an AB towards threat before treatment, which calls into question its applicability, as there is no point in giving threat-avoidance training to an anxious person who is already avoidant (Van Bockstaele et al., 2014). In one study, almost a half of anxious children recruited for ABM-threat-avoidance training were excluded because they showed no pre-existing bias towards threat (Eldar et al., 2012). However, this problem does not apply to all types of ABM. Another approach encourages active attention search for positive cues (*ABM-positive-search training*) and is potentially suitable for all anxious individuals (see Fig. 1, lower panel). It uses a visual-search task which presents arrays of pictures and, in each array, one picture is positive (e.g., smiling face) and the others are negative or threat-related (e.g., angry or frowning faces; Dandeneau, Baldwin, Baccus, Sakellaropoulos, & Pruessner, 2007; De Voogd, Wiers, Prins, & Salemink, 2014; Waters, Pittaway, Mogg, Bradley, & Pine, 2013; Waters et al., 2015; Waters, et al., 2016). Participants are instructed to search for the positive image and ignore the others.

### 1.3. Therapeutic effectiveness of ABM

While preliminary reports on the efficacy of ABM in reducing anxiety and stress reactivity were promising (e.g., MacLeod et al., 2002; Amir, Beard, Burns, & Bomyea, 2009), other studies reported null effects or replication failures (e.g., Carleton et al., 2015; Harris & Menzies, 1998; Heeren, Mogoase, McNally, Schmitz, & Philippot, 2015; Julian, Beard, Schmidt, Powers, & Smits, 2012; McNally, Enock, Tsai, & Tousian, 2013; Rapee et al., 2013). Recent meta-analyses and reviews of random controlled trials (RCTs) report small-to-moderate effect sizes of ABM on anxiety symptoms (Cristea, Kok et al., 2015; Cristea, Mogoase et al., 2015; Hakamata et al., 2010; Hallion & Ruscio, 2011; Heeren, Mogoase, Philippot et al., 2015; Mogoase et al., 2014; Van Bockstaele et al., 2014). However, effects of ABM on anxiety may be nonsignificant when outliers and publication bias are taken into account (Cristea, Kok et al., 2015; Cristea, Mogoase et al., 2015; Van Bockstaele et al., 2014) and when follow-up data are evaluated (Heeren, Mogoase, Philippot et al., 2015). The efficacy of ABM-threat-avoidance training seems particularly disappointing when delivered in home-based, rather than laboratory or clinic settings (Cristea, Kok et al., 2015; MacLeod & Clarke, 2015). These findings question the usefulness of ABM in treating anxiety disorders (Cristea, Kok et al., 2015; Cristea, Mogoase et al., 2015; Emmelkamp, 2012; Heeren, Mogoase, Philippot et al., 2015; Koster & Bernstein, 2015; Lau, 2015; Mogoase et al. 2014).

Much of this research used ABM-threat-avoidance training. For example, the meta-analysis by Mogoase et al. (2014), which found a small effect of ABM on symptoms, examined 43 controlled trials, with over 2000 participants providing 47 group comparisons. Of these comparisons, 42 (91%) used visual-probe or spatial-cueing training tasks, and five (9%) used ABM-

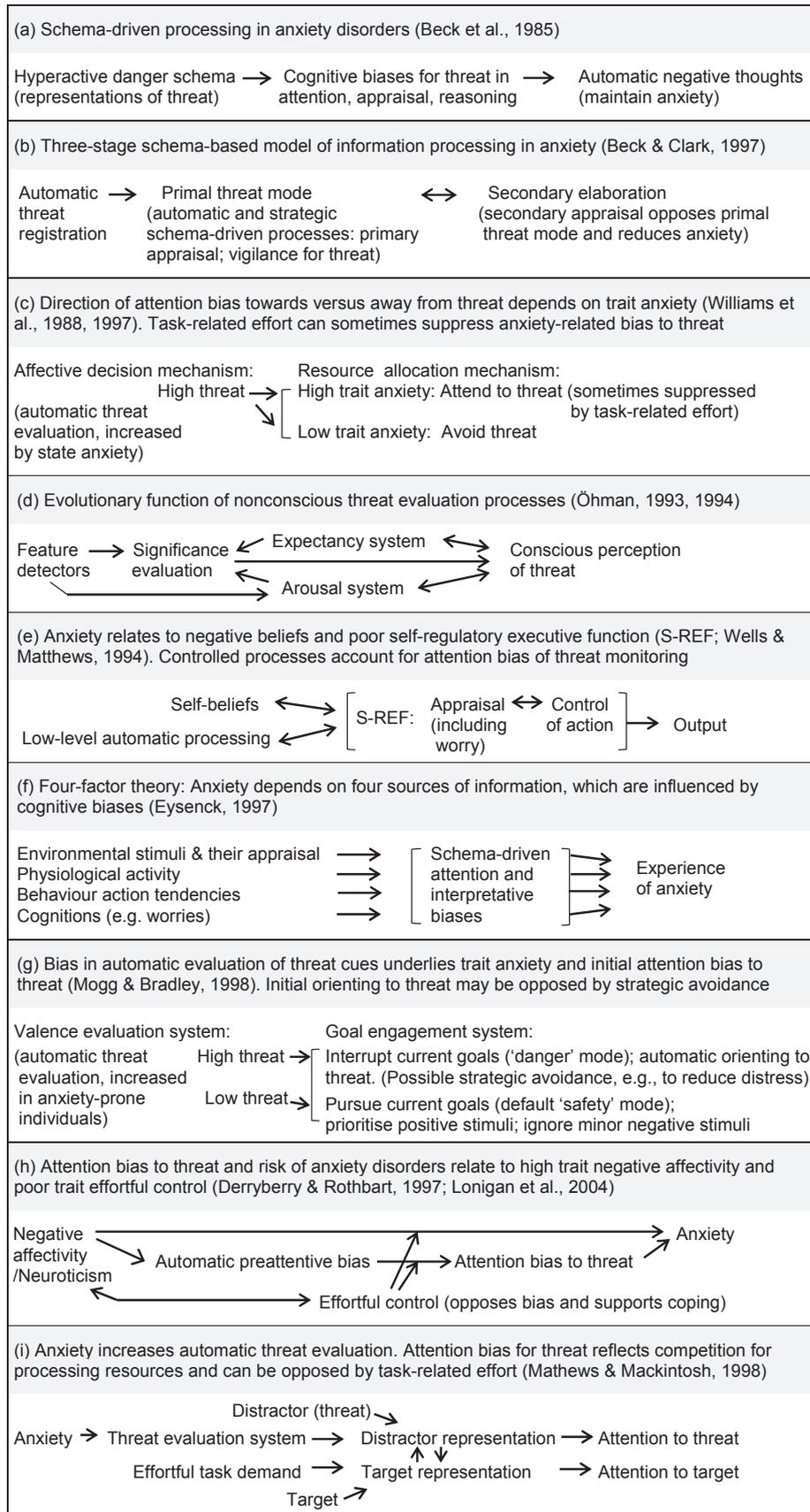


Fig. 2. Examples of cognitive views of relationship between attention and anxiety.

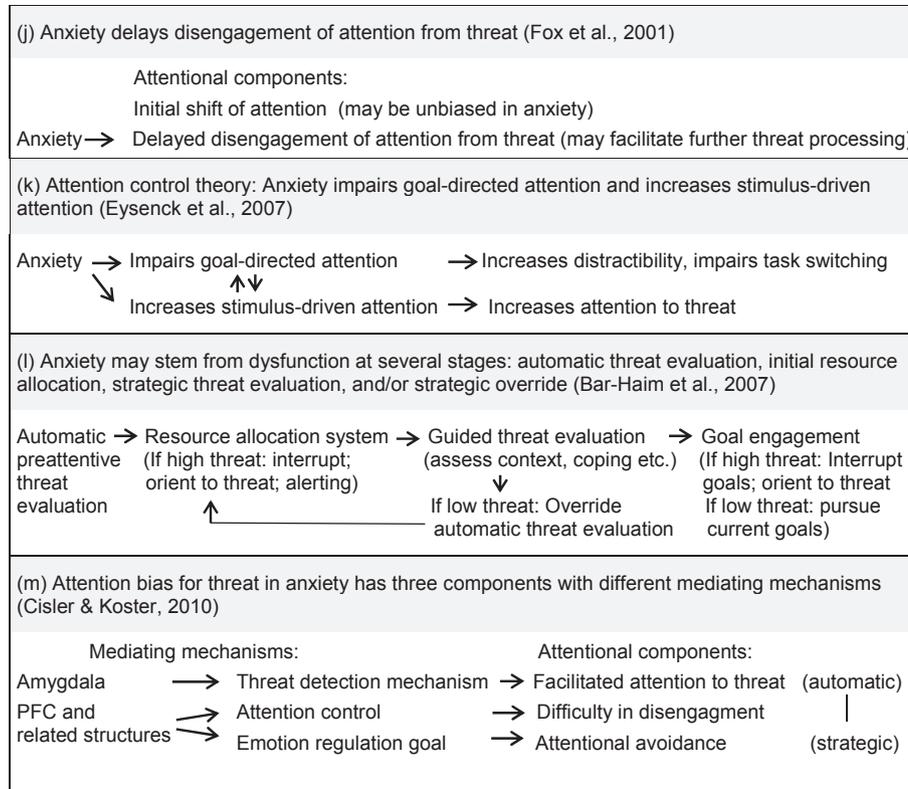


Fig. 2. (Continued)

positive-search training. This meta-analysis indicated that symptom-improvement effect sizes of several comparisons which used ABM-positive-search training were larger than the average effect size of the whole dataset (Dandeneau et al., 2007; Study 3a and 3b; Waters et al., 2013). Only one study in the meta-analysis used ABM-positive-search training with a clinically anxious sample, and that showed significant improvement in anxiety symptoms (Waters et al., 2013). Two subsequent clinical studies similarly indicate a promising effect of ABM-positive-search training (delivered at home) in treating anxiety disorders (Waters, et al., 2015; Waters, et al., 2016). Thus, the disappointing findings of ABM may apply mainly to ABM-threat-avoidance training. To consider how ABM may be improved, it is helpful to examine theoretical views of the cognitive mechanisms which contribute to anxiety, and variables which influence AB to threat.

## 2. Diverse cognitive views of the role of attention in anxiety

This section briefly considers various cognitive views of the relationship between anxiety and attention processes, outlined in Fig. 2. These models commonly distinguish between automatic and strategic processes. *Automatic* typically refers to rapid, unintentional, uncontrolled processes outside awareness (also described as *bottom-up* or *stimulus-driven*); whereas *strategic* refers to more controllable, intentional, and conscious processes (also described as *top-down*, or *goal-directed*; Isen & Diamond, 1989; Schneider & Shiffrin, 1977). The distinction has been subject to debate, as some features may overlap and operate along continua (Moors & De Houwer, 2006; Isen & Diamond, 1989). Nevertheless, reviews of empirical evidence indicate that anxiety disorders are associated with automatic processing biases for threat information (Bar-Haim et al., 2007; Teachman, Joormann, Steinman, & Gotlib, 2012) and

most cognitive models of anxiety predict the existence of such biases.

### 2.1. Automatic and strategic schema-based processing in anxiety (Beck & Clark, 1997; Beck, Emery & Greenberg, 1985)

According to Beck et al.'s (1985) schema model, anxiety is characterised by hypervalent danger schemas (cognitive representations of threat) which act as a filter on information processing, resulting in interpretative, attentional and memory biases which favour threat-related information. These cognitive biases give rise to negative thoughts and images, which in turn contribute to the experience of anxiety (Fig. 2a). This schema model has been highly influential in underpinning the use of CBT for anxiety. Subsequently, Beck and Clark (1997) identified three key stages of information-processing in anxiety: (i) *automatic threat registration* (orienting mode), which operates outside awareness and serves as an early warning threat detection system; (ii) *primal threat mode* which is a mixture of automatic and strategic schema-driven processing, including initial stimulus appraisal, hypervigilance for threat, and negative automatic thoughts, and (iii) *secondary elaboration*, which includes effortful, elaborative reappraisal of the stimulus context and the individual's coping resources (Fig. 2b). Beck and Clark propose that anxiety reflects the ineffective use of effortful processing in counteracting threat-related schema-driven processing. Moreover, verbally mediated interventions help promote constructive cognitive modes of processing. However, Williams et al. (1988) note that schema models did not predict empirical findings that anxiety seems more closely related to bias to threat in early attentional processes than in later elaborative memory processes (e.g., MacLeod et al., 1986; Mathews & MacLeod, 1985; Mogg, Mathews, & Weinman, 1987), which Williams et al. sought to address in their model.

2.2. *Direction of AB towards versus away from threat depends on trait anxiety (Williams et al., 1988, 1997), and task-related effort can sometimes suppress anxiety-related AB to threat*

Williams et al. (1988, 1997) highlight the relationship between the direction of AB and trait anxiety (Fig. 2c). They proposed that, at an early automatic stage of processing, an *affective decision mechanism* assesses the threat value of stimuli, which is increased by state anxiety. Its output feeds into a *resource allocation mechanism* which determines the direction of attentional responses to threat, depending on an individual's trait anxiety level. Specifically, high trait anxious individuals have an enduring tendency to direct attention towards threat, whereas low trait anxious individuals have a bias to direct attention away from threat (i.e., attentional avoidance). The model proposes that these different patterns of bias operate automatically and become more pronounced as stimulus threat value, or state anxiety, increases. This model also suggests that early AB towards threat increases vulnerability to and maintenance of anxiety disorders. It also predicts that early AB to threat characterises anxiety, while negative bias in later elaborative processes relates more to depression (see Section 4.4.3).

In 1997, Williams et al. reviewed evidence for their 1988 model and discussed AB within a parallel distributed processing framework (e.g., in terms of competing pathways for processing threat-related and task-relevant information). This explained how high trait anxious individuals can sometimes override AB to threat by increasing effort allocated to task-relevant processing; whereas clinically anxious individuals seemed unable to override their AB. According to the 1997 model, “clinical conditions represent a breakdown in this override” of anxiety-related AB to threat, resulting in further symptoms such as worry (p. 132). Evidence of this override in nonclinical anxiety included unexpected findings from the modified Stroop task, which showed that AB for fear-relevant words in nonclinical snake phobia was suppressed by fear induction by the presence of a snake (Mathews & Sebastian, 1993). AB suppression was associated with faster RTs, consistent with increased effort expended on task-relevant processing (referred to as the *task-related effort* hypothesis; Constans, McCloskey, Vasterling, Brailey, & Mathews, 2004). However, the conditions which suppress AB to threat in anxious individuals are unclear, as stressors have variable effects on AB (see Section 4.4.4).

The model has also been questioned as it predicts that low trait anxious individuals show increasing avoidance as stimulus threat value increases. However, low trait anxious individuals are unlikely to direct attention away from severe or real threats; instead, as stimulus threat value increases, low trait anxious individuals show greater attention to threat, rather than greater avoidance (Mogg & Bradley, 1998; Mogg, Bradley et al., 2000; Mogg, McNamara et al., 2000; Mogg, Millar, Bradley, 2000; Wilson & MacLeod, 2003). Furthermore, meta-analytic evidence of attention avoidance of threat cues in low trait anxiety is weak and inconsistent (Bar-Haim et al. 2007).

2.3. *Evolutionary function of nonconscious threat evaluation processes (Öhman, 1993, 1994)*

Öhman's (1993, 1994) model proposes that fear and anxiety depend on a specialised cognitive mechanism which has evolved to detect danger (Fig. 2d). Two of its components are involved in stimulus-analysis: *feature detectors* and *significance evaluator*, which both operate automatically outside awareness. Feature detectors are sensitive to the perceptual characteristics of biologically fear-relevant stimuli (e.g., snakes, spiders, angry faces). When activated, they automatically trigger arousal and attention capture. The significance evaluator monitors incoming stimuli for a wider

range of potential threats. It is influenced not only by bottom-up inputs from feature detectors, but also by top-down inputs from an *expectancy system* which reflects past memories and experience. Thus, AB to phobic images (e.g., spiders) may relate primarily to activation of feature detectors, while AB to symbolic threat cues (e.g., threat words) in anxiety disorders may relate to bias from the expectancy system on the significance evaluator. The significance evaluator is also activated by the *arousal system*, which may account for state anxiety increasing attention to threat. Integration of information from the significance evaluator, expectancy, and arousal systems feeds into a *conscious perception system*, resulting in the conscious perception of threat.

Evidence of automatic threat evaluation includes physiological responses to pictures of masked fear-related stimuli (e.g., snakes, spiders; Öhman & Soares, 1993, 1994), and amygdala response to unattended or masked threat cues such as fearful or angry faces (e.g., Dolan & Vuilleumier, 2003; LeDoux, 1996; Monk et al., 2008; see Section 4.3.1). Some specific details of Öhman's (1993) model have been queried based on later empirical findings; e.g., van den Hout, de Jong, and Kindt (2000) proposed that the significance evaluator can directly trigger arousal responses outside awareness, as suggested by physiological responses to masked threat words. Nonetheless, the model's emphasis on automatic threat-evaluation processes has been influential (e.g., Mathews & Mackintosh, 1998; Mogg & Bradley, 1998).

2.4. *Anxiety stems from negative beliefs and poor self-regulatory executive function (Wells & Matthews, 1994)*

Wells and Matthews' (1994) model of *self-regulatory executive function* (S-REF) emphasises the role of strategic processes in anxiety and AB (Fig. 2e). It distinguishes three levels of processing: (i) low-level automatic processes, (ii) controlled processes including conscious appraisal and attention control, which support regulation of thought and behaviour; i.e., S-REF, and (iii) beliefs, which guide controlled process. Trait anxiety is characterised by negative beliefs and dysfunctional S-REF activity, which includes conscious negative appraisals and threat monitoring. AB for threat in anxiety is explained by controlled processes. Thus, the model cannot account for anxiety-related biases in automatic processing of threat (for evidence of such biases, see reviews by Bar-Haim et al., 2007; Teachman et al., 2012).

2.5. *Four-factor theory: anxiety depends on four sources of information influenced by cognitive biases (Eysenck, 1997)*

Eysenck (1992) proposed that *hypervigilance* underlies AB for threat and increased general distractibility in both high trait anxiety and generalised anxiety disorder. Hypervigilance is a latent vulnerability factor for anxiety, so is more apparent under conditions of high stress or state anxiety. This view was developed into Eysenck's (1997) *four-factor theory* which proposed that four sources of information contribute to anxiety: external stimuli, physiological activity, behaviour action tendencies, and cognitions such as worries (Fig. 2f). Individual differences in anxiety depend on attention and interpretation biases, which are guided by schemas (e.g., memory representations of danger) and applied to these four sources of information. High trait anxious individuals have attention and interpretation biases favouring threat information, repressors (low trait anxious individuals with high social desirability scores) have opposite biases, and low trait anxious individuals (who have low social desirability scores) have no biases. Furthermore, different anxiety disorders have different predisposing factors that reflect the relative importance of the four sources of information. For example, attention and interpretation biases for

internal body sensations may primarily contribute to panic disorder, whereas attention and interpretative biases for all four sources of information contribute to high trait anxiety and generalised anxiety disorder. Eysenck (2004) discusses limitations of four-factor theory, such as inconsistent evidence of opposite attention and interpretative biases in repressors.

*2.6. Bias in automatic threat evaluation underlies trait anxiety and initial AB to threat, which may be followed by strategic avoidance (Mogg & Bradley, 1998)*

Our cognitive-motivational analysis proposed that anxiety vulnerability stems mainly from a bias in automatic threat evaluation, rather than the direction of AB (as proposed by Williams et al., 1988, 1997). It posits that stimulus threat value is automatically assessed by a *valence evaluation system*, influenced by several variables (stimulus features, context, prior learning, state and trait anxiety). This system is more reactive to threat cues in anxiety-prone individuals. Its output feeds into a *goal engagement system* which, in the absence of threat, focuses on processing goal-relevant stimuli and inhibits processing of minor task-irrelevant negative cues (Fig. 2g). However, if the valence evaluation system judges a stimulus to have high threat value, this triggers automatic attention to the threat and interruption of goal-related activity. As anxiety-prone individuals tend to evaluate mild threat cues as having high motivational salience, they are more likely to direct attention to those cues. Hence, AB to mild threat cues may be an index of anxiety-proneness. It may also maintain anxiety, as anxiety-prone individuals are more likely to notice minor threat cues in the environment, which enhances their perception of the world as aversive and unsafe, and increases their state anxiety.

The model also incorporates the *vigilance-avoidance hypothesis* (Mogg et al., 1987): i.e., the initial AB towards threat may be opposed by avoidance in controlled attention strategies, which may reflect an attempt to reduce subjective discomfort or danger (e.g., averting gaze from horrific scene, escape); so avoidance may be more apparent at higher levels of threat or anxiety. Thus, “the focus of attention of anxious individuals may be unstable, with a tendency to shift attention repeatedly towards and away from threat” (p. 820). While avoidant attention strategies may reduce immediate distress, they may be unhelpful in the long-term by interfering with habituation and thus maintaining anxiety. It was also noted that controlled attention processes may not only underlie threat avoidance in anxiety, but also maintenance of attention on negative information in depression (Bradley, Mogg, & Lee, 1997).

The model proposes that attention is automatically directed to stimuli that are evaluated as having high subjective threat salience for the individual, and it differs from Williams et al.'s (1997) model in predicting that both high and low anxious individuals show greater attention to highly salient threat than mild threat stimuli (supportive evidence includes Mogg, Bradley et al., 2000; Mogg, McNamara et al., 2000; Mogg, Millar et al., 2000; Wilson & MacLeod, 2003). Regarding the vigilance-avoidance hypothesis, while many studies indicate enhanced initial AB to threat in anxiety (e.g., Bar-Haim et al., 2007), evidence of avoidance is more limited and variable (e.g., for a review see Cisler & Koster, 2010; variables influencing ABs towards and away from threat are discussed later, Sections 4.4.2–4.4.6).

*2.7. Trait negative affectivity and poor effortful control contribute to AB and risk of anxiety (Derryberry & Rothbart, 1997; Lonigan, Vasey, Phillips & Hazen, 2004)*

Developmental research indicates that risk of emotional disorders is higher in individuals with high trait negative affectivity

(including anxious/fearful temperament) and lower in those with high trait effortful control (Derryberry & Rothbart, 1997; Rothbart, Derryberry, & Posner, 1994). Effortful control is a stable trait which depends on attention and inhibitory control processes that support effortful regulation of emotional and motivational functions, e.g., by allowing individuals to allocate attention flexibility, decrease attention to negative cues, and increase attention to positive information (Derryberry & Rothbart, 1997). Consequently, AB for threat reflects conflicting influences of fearful/anxious temperament (which enhances cognitive representations of threat) and trait effortful control, which opposes the allocation of attention to task-irrelevant threat stimuli (Derryberry & Rothbart, 1997). Lonigan et al. (2004) elaborated on this developmental view and argued that, under conditions which do not allow effortful attention control (e.g., brief masked stimuli), individuals with high trait negative affectivity show an automatic preattentive processing bias for threat (Fig. 2h). However, if conditions allow attention control to modify this initial bias, the resulting AB towards threat may be more variable and likely to depend on individual differences in trait attention control. Tests of the proposal that trait attention control moderates the relationship between anxiety and AB for threat have provided some support (e.g., Derryberry & Reed, 2002; Lonigan & Vasey, 2009; Susa, Benga, Pitica, & Miclea, 2014; see also Section 4.4.5).

*2.8. AB to threat in anxiety depends on automatic threat evaluation and is sometimes suppressed by task-related effort (Mathews & Mackintosh, 1998)*

Mathews and Mackintosh's (1998) model shares features with other models (Fig. 2i): e.g., while anxious individuals may show greater AB for mild threats than low anxious individuals, both high and low anxious individuals are likely to direct attention to severe threats (which, as noted by Mathews and Mackintosh, is consistent with Mogg & Bradley, 1998, but not Williams et al., 1988, 1997; see Sections 2.2 and 2.6). Also, anxious individuals can sometimes suppress AB by task-related effort (consistent with aspects of Williams, Watts, MacLeod, & Mathews, 1997). The model suggests that anxiety increases output of an automatic threat evaluation system, resulting in greater activation of representations of threat cues. Consequently, when task-relevant target stimuli and threat distractors compete for later processing resources, the latter are more likely to capture attention and interfere with performance in anxious individuals. However, this effect also depends on voluntary effort expended on task-relevant processing. Under certain conditions, such as high situational stress or high task demand, anxious individuals may be able to recruit sufficient voluntary effort (reflected by general RT speeding) to increase attention to task-relevant stimuli and ignore threat (e.g., AB suppression on modified Stroop task; Mathews & Sebastian, 1993). The model suggests that failure to suppress AB under stress may explain some symptoms of clinical anxiety (for discussion of evidence of mixed effects of stressors on anxiety-related ABs, see Section 4.4.4).

*2.9. Difficulty in disengagement of attention from threat in anxiety (Fox et al. 2001)*

Drawing on Posner and Petersen's (1990) spotlight model of attention, which identified three distinct components of visual orienting (shift, engagement, disengagement), Fox et al. (2001) examined whether AB in anxiety is evident in both initial shifting of spatial attention to threat and difficulty in disengaging attention from threat. The *delayed disengagement hypothesis* was tested in experiments using the emotional spatial-cueing task with briefly presented threat and neutral cues (e.g. 100–250 ms). High state

anxious individuals were slower to respond to probes that appeared in a different location to threat cues (invalid-threat; Fig. 1, middle panel), than to probes that appeared in a different location to nonthreat cues (invalid-nonthreat), suggesting difficulty disengaging spatial attention from threat. The valid-cue conditions did not reveal anxiety-related bias in shifting attention to threat. Fox et al. (2001) suggested that anxiety is associated mainly with increased attentional dwelling on threat cues, which may serve to facilitate identification and more detailed evaluation of potential threats; and this short-term increase in dwell time on threat may relate to worry and rumination. However, a recent clinical study found that individuals with generalised anxiety disorder show the opposite effect (faster RTs on invalid-threat than invalid-nonthreat trials) suggesting threat avoidance (Yiend et al., 2015; see Van Bockstaele et al., 2014; for a review of related findings). The mechanisms underlying such findings have been subject to debate, which will be discussed after considering recent models of attention and cognitive control (see Sections 3 and 4.4.1).

#### 2.10. Attention control theory: anxiety impairs goal-directed attention and increases stimulus-driven attention (Eysenck, Derakshan, Santos, & Calvo, 2007)

According to attention control theory, anxiety not only increases attention to threat, but also impairs attention control (Fig. 2k). This theory draws on Corbetta and Shulman's (2002) distinction between stimulus-driven and goal-directed attention systems, and Miyake et al.'s (2000) distinction between core executive functions of inhibition, shifting (i.e., task-switching or set-shifting), and updating working memory (see Sections 3.4 and 3.7 for further details of these models). Eysenck et al. (2007) propose that anxiety changes the balance between bottom-up and top-down attention systems. I.e., anxiety strengthens the stimulus-driven attention system, which reacts automatically to task-irrelevant salient stimuli and facilitates attention to threat. It also impairs the goal-directed attentional system, which supports two key attention control functions: inhibition of task-irrelevant information and responses, and switching between tasks or sets (see Berggren & Derakshan, 2013; Snyder, Miyake, & Hankin, 2015; for reviews of evidence; see also Section 3.10). They suggest that poor attention control contributes to difficulty disengaging attention from task-irrelevant threat, as "effective attentional control would involve rapid disengagement" from distractors (p. 346).

According to this theory, updating (manipulating and monitoring the contents of working memory) may be unaffected by anxiety under low stress conditions, as this executive function relates more to transient storage of information rather than attention control; although updating may be impaired by anxiety under high stress conditions which reduce the efficiency of executive control processes. Some recent evidence suggests that anxiety enhances working memory storage of task-irrelevant threat information; with anxiety and worry being related to greater difficulty in filtering out task-irrelevant threat cues from working memory (Stout, Shackman, & Larson, 2013; Stout, Shackman, Johnson, & Larson, 2015). Attention control theory emphasises the impairing effect of anxiety on attention control, and complements other theories, which focus more on the adaptive role of trait attention control in protecting against anxiety (e.g., Derryberry & Rothbart, 1997; Lonigan et al., 2004; see Section 2.7).

#### 2.11. Multiple dysfunctions in threat processing may underlie anxiety (Bar-Haim et al., 2007)

Bar-Haim et al. (2007) put forward a model (Fig. 2l) which integrated their meta-analytic findings of AB in anxiety with

proposals from prior cognitive theories (Mogg & Bradley, 1998; Wells & Matthews, 1994; Williams et al., 1988, 1997). They suggest that high trait and clinical anxiety stem from dysfunction in one or more of four aspects of processing: (i) *preattentive threat evaluation system*, which may be biased to automatically overestimate the threat value of mild threat cues; (ii) *initial resource allocation system*, which may be oversensitive to mild threat cues, and (when activated by threat) interrupts ongoing activity and triggers alerting, initial orienting to threat and a conscious anxious state; (iii) *guided threat evaluation system*, which supports reappraisal based on more detailed elaborative analysis of stimulus context, prior learning and coping resources, and which may be biased to produce conscious over-evaluation of threat, and (iv) *override mechanism*, a feedback process triggered when the guided threat evaluation system reappraises the stimulus as low threat, which opposes the effects of automatic threat evaluation, and which may be deficient in anxiety. Bar-Haim et al. suggest that malfunctions in each of these mechanisms may contribute to differing degrees in different anxiety disorders; e.g., specific fear disorders may be characterised by automatic over-evaluation of the threat value of phobia-related stimuli, excessive alerting in initial resource allocation, and deficient strategic override; but normal functioning of the conscious guided threat evaluation system. This model describes cognitive mechanisms underlying AB towards threat (identified in the meta-analysis), rather than those underlying anxiety-related threat avoidance, which is sometimes found in empirical studies (e.g., reviews by Armstrong & Olatunji, 2012; Cisler & Koster, 2010).

#### 2.12. Three components of AB in anxiety: Facilitated attention, disengagement difficulty, and avoidance (Cisler & Koster, 2010)

Following their review of cognitive models of anxiety and evidence of ABs, Cisler and Koster (2010) propose that AB in anxiety has three observable components (Fig. 2m). *Facilitated attention* refers to attention being drawn towards threat ("i.e., attention orienting", p. 208) and is largely mediated by an automatic amygdala-based threat detection mechanism. *Difficulty in disengaging attention* from threat may follow facilitated attention to threat, and refers to "the degree to which a threat stimulus captures attention and impairs switching attention from the threat to another stimulus" (p. 208, italics in original). This resembles the delayed disengagement hypothesis of Fox et al. (2001), although Cisler and Koster suggest that difficulty in disengaging attention from threat primarily results from poor top-down attention control mediated by the prefrontal cortex (see also Eysenck et al., 2007). *Attention avoidance* refers to attention being directed away from the spatial location of a threat cue, which may reflect an emotion regulation strategy (similar to the vigilance-avoidance hypothesis, Mogg & Bradley, 1998); this is also likely to be mediated by prefrontal cortical regions. With regard to treatment implications, Cisler and Koster note that ABM-threat-avoidance training may encourage strategic avoidance of threat (which may be unhelpful for anxious individuals), or reduce difficulty in disengaging attention from threat (which may be beneficial). They highlight the need for research to examine the effects of ABM on different AB components.

#### 2.13. Overview of diverse views of cognitive mechanisms in anxiety

The preceding section illustrates a diversity of views regarding the cognitive mechanisms involved in threat processing in anxiety (Fig. 2). Nevertheless, several common themes emerge, including proposals that AB to threat (i) is a correlate of anxiety, (ii) may maintain anxiety, (iii) is supported by an interplay of automatic (bottom-up) and controlled (goal-directed, top-down) processes,

(iv) is triggered by an automatic threat evaluation system which overestimates the threat value of stimuli in anxiety, (v) is evident from biases towards and away from threat cues on spatial attention tasks (e.g., visual-probe task); (vi) is reflected by interference in task performance from task-irrelevant threat cues (e.g., on the modified Stroop task), and (vii) can be modified by controlled attention processes.

Cognitive models indicate several ways in which controlled attention strategies may relate to AB and anxiety. For example, (i) trait attention control may oppose an automatic AB towards threat and reduce vulnerability to anxiety (Derryberry & Rothbart, 1997; Lonigan et al., 2004). (ii) Attention control (in particular, inhibition and task-switching functions) may be impaired by anxiety (Eysenck et al., 2007). (iii) Under certain conditions, such as high task demands or external stressors, voluntary task-related effort may sometimes suppress processing of threat distractors in anxious individuals (Mathews & Mackintosh, 1998; Williams et al., 1997, 1996). (iv) Strategic attention processes may underlie attentional avoidance of threat in anxious individuals, e.g., in an attempt to reduce subjective discomfort elicited by aversive stimuli (Cisler & Koster, 2010; Mogg & Bradley, 1998). (v) Strategic attention processes may also contribute to prolonged dwelling on negative information (e.g., to facilitate its more extensive elaborative processing), associated with anxiety, depression or their combination (Armstrong & Olatunji, 2012; Bradley et al., 1997; Fox et al., 2001).

Cognitive models seek to explain differing manifestations of ABs on spatial attentional tasks which include (i) *initial orienting to threat*, (ii) *maintaining attention on threat*, and (iii) *avoidance of threat*. Another manifestation of AB is (iv) *threat-distractor interference*; i.e., the interference effect of threat cues on task performance, reflecting competition in processing task-relevant information and task-irrelevant threat which can occur independently of spatial orienting (e.g., on modified Stroop task). These AB indices may reflect differing degrees of influence of bottom-up and top-down mechanisms involved in threat evaluation, spatial orienting and inhibitory processing. This analysis extends Cisler and Koster's (2010) framework which focused on three components of AB (facilitated attention, disengagement difficulty, threat avoidance). Distinguishing between manifestations of ABs in spatial orienting and threat-distractor interference may help clarify the mechanisms involved in ABs and ABM, discussed later (Sections 4.4.1 and 5.4, respectively).

Cognitive models suggest that vulnerability to anxiety relates to dysfunction in several mechanisms, including biases in bottom-up processes of automatic threat evaluation and automatic initial orienting to threat, and disturbance in top-down cognitive control processes, including controlled attention, elaboration, and override of bottom-up biases (e.g., Bar-Haim et al., 2007; Beck & Clark, 1997; Derryberry & Rothbart, 1997; Eysenck et al., 2007; Lonigan et al., 2004; Mogg & Bradley, 1998; Wells & Matthews, 1994; Williams et al., 1988; 1997). Each of these perturbations may contribute to anxiety (Bar-Haim et al., 2007). These differing views point to a potential limitation of ABM-threat-avoidance training which focuses on modifying an automatic bias in initial orienting to threat (MacLeod et al., 2002), rather than other attention mechanisms such as top-down attention control which may support emotion regulation and resilience to anxiety (e.g., Derryberry & Rothbart, 1997).

While none of the models reviewed earlier provides a complete account of threat processing in anxiety, they make important contributions by describing key ideas which may be integrated into a framework for guiding the development of treatments such as ABM. Before doing so, it is helpful to briefly consider theories of attention and cognitive control which have shaped previous cognitive models of anxiety and the framework proposed here.

### 3. Models of attention and executive control systems

Models of attention and cognitive control have undergone substantial changes in recent years informed by research findings in cognitive psychology and neuroscience. These models often seem conflicting, with some describing two main attention systems (Corbetta & Shulman, 2002; Desimone & Duncan, 1995), whereas others identify three (Posner & Petersen, 1990) or five systems (Petersen & Posner, 2012). This raises the question of what are the core attention processes that contribute to ABs in anxiety. A detailed review of research into attention and cognitive control is beyond the scope of this article. Instead, we focus on key ideas which have been influential in cognitive models of anxiety, and which guide the choice of components of our framework. Fig. 3a illustrates distinctions between various attention and cognitive control functions, and correspondences between theoretical views. Fig. 3b indicates core functions identified by these models, which correspond to those in our framework (described in Section 4 and Fig. 4), and gives examples of possible effects of threat and anxiety on these core functions.

#### 3.1. Automatic detection and controlled search (Schneider & Shiffrin, 1977)

About forty years ago, Schneider and Shiffrin (1977) identified two key mechanisms in attention: (i) *automatic detection*, which underlies automatic attention responses, involves parallel perceptual processing, is independent of cognitive load, and outside the individual's control, and (ii) *controlled search*, which is capacity-limited, influenced by cognitive load, tends to be serial in nature, and controlled by the individual. As noted earlier, the automatic-controlled distinction is incorporated into most cognitive models of anxiety.

#### 3.2. Spotlight model of attention (Posner & Petersen, 1990)

Another influential view was Posner and Petersen's (1990) model which described three main attention systems: (i) *Alerting*, which maintains a vigilant alert state and facilitates rapid responses to external stimuli, (ii) *Orienting* to sensory events, and (iii) *Detecting* signals for conscious focal processing. Attentional selection of information was likened to a *spotlight* and orienting comprised separate three functions: *disengage* from the current focus of attention, *shift* attention to new location, and *engage* attention on the new target location. Neurophysiological data available at that time suggested that disengage, shift and engage functions were distinct mechanisms supported by different brain regions (parietal cortex, colliculus and pulvinar, respectively). This model of orienting has guided research into shift and disengagement components of AB to threat in anxiety (e.g., Bar-Haim et al., 2011; Derryberry & Rothbart, 1997; Fox et al., 2001; Yiend et al., 2015). However, it has since been updated by Petersen and Posner (2012), described later (Section 3.6).

#### 3.3. Biased-competition model of attention (Desimone & Duncan, 1995)

Another milestone is Desimone and Duncan's (1995) biased-competition model of attention, which challenges the spotlight model. They proposed that representations of objects compete for processing resources in multiple points of the visual processing system, including bottom-up stimulus-driven mechanisms which, for example, respond to moving, bright or novel stimuli; and higher-level top-down control mechanisms which select objects for visual processing according to their relevance to current behaviour.

<b>(a) Models of attention and executive control systems relevant to attention biases in anxiety</b>										
Posner & Petersen (1990)		<b>Alerting</b> Maintain vigilant state	<b>Orienting</b> (posterior attention system) Shift - Engagement - Disengagement			<b>Detecting</b> (anterior attention system) Selection for focal conscious processing				
Desimone & Duncan (1995)	<b>Bottom-up stimulus-driven mechanisms</b> bias competition for attention-selection according to stimulus attributes (e.g., novel stimuli)				<b>Top-down cognitive control mechanisms</b> bias competition for attention-selection according to relevance of stimuli to current behaviour					
Corbetta & Shulman (2002)		<b>Stimulus-driven attention</b> (ventral frontoparietal network) Alerting Interrupt Stimulus-driven orienting			<b>Goal-directed attention</b> (dorsal frontoparietal network) Goal-directed orienting Select goal-related stimuli & responses Maintain & switch task sets					
Lavie (2005)	<b>Perceptual competition</b>				<b>Competition in cognitive control processes</b>					
Duncan (2010)					<b>Multiple demand system</b> Common cognitive control system to support goal-directed processes					
Petersen & Posner (2012)		<b>Alerting network</b> (NA system & locus coeruleus)	<b>Orienting networks</b> <b>Bottom-up orienting</b> (ventral frontoparietal)		<b>Top-down orienting</b> (dorsal frontoparietal)	<b>Executive control networks</b> <b>Moment-to-moment task control</b> (frontoparietal control)			<b>Maintaining task set</b> (cingulo-opercular)	
Miyake et al. (2000) Friedman & Miyake (2004)					<b>Common executive function factor</b> <b>Inhibition</b> of responses and distractors; resist memory intrusions				<b>Shifting</b> Set shifting; task switching	<b>Updating</b> working memory
Miyake & Friedman (2012)					<b>Common executive function factor</b> including <b>Inhibition</b>			<b>Shifting</b>	<b>Updating</b>	
Diamond (2013)					<b>Higher-level executive functions</b> (planning, problem-solving, reasoning)					
					<b>Inhibitory control</b>	<b>Cognitive flexibility</b>	<b>Working memory</b>			
<b>(b) Bottom-up and top-down cognitive functions involved in threat processing and anxiety</b>										
<b>Core cognitive functions</b>  (based on above models)	<b>Bottom-up /stimulus-driven processes</b>				<b>Top-down attention and cognitive control processes</b>					
	<b>Perceptual analyses</b>	<b>Alerting</b>	<b>Interrupt</b>	<b>Bottom-up orienting</b>	<b>Top-down orienting</b>	<b>Goal-directed inhibitory control</b>	<b>Cognitive flexibility</b>	<b>Working memory</b>		
	Examples of effects of threat or anxiety on cognitive functions	Enhanced perceptual processing of threat	Speeding effect of state anxiety or threat on responses	Automatic interference effect of threat on responses	Automatic spatial orienting towards threat	Strategic biases in orienting to, holding attention on, and avoiding threat	Difficulty ignoring threat distractors; increased general distractibility in anxiety	Task switching impaired by threat or anxiety	Difficulty filtering task-irrelevant threat information from working memory	

Fig. 3. Attention and cognitive control mechanisms. (a) Models of attention and executive control functions relevant to attention biases in anxiety (NA = noradrenaline). (b) Bottom-up and top-down cognitive functions involved in threat processing and anxiety.

Multiple representations of visual objects are constructed in parallel within the visual system before one specific object is selected; and selection is biased by both bottom-up and top-down control

processes. Attention is viewed as an *emergent property* of multiple mechanisms competing for processing resources and control of behaviour. This biased-competition account is widely included in

subsequent models of attention.

#### 3.4. Stimulus-driven and goal-directed attention (Corbetta & Shulman, 2002)

Based on their review of cognitive neuroscience evidence, Corbetta and Shulman (2002) described two main attention systems: *goal-directed* and *stimulus-driven* attention. The goal-directed system co-ordinates selection of task-relevant stimuli and responses, maintains task sets, and biases activity in cortical regions to enhance perceptual processing of task-relevant stimuli (see also Gilbert & Sigman, 2007). The stimulus-driven system directs attention to salient or unexpected stimuli, and acts as a *circuit-breaker* on goal-directed attention, thereby allowing an unattended salient stimulus to interrupt ongoing task-relevant activity and automatically attract attention. The two attention systems are associated with different brain regions, with a largely right-lateralised ventral frontoparietal network supporting stimulus-driven attention; and a dorsal frontoparietal network involved in goal-directed attention.

#### 3.5. Selective attention in perceptual and cognitive control processes (Lavie, 2005)

There is a long-standing debate about whether attention-selection mechanisms operate in both perceptual and cognitive control processes (i.e., early vs. late selection debate; see Driver, 2001; for a review). One recent influential view is *load theory* (Lavie, 2005, 2010), which proposes that attention selection operates at each level of processing (which is capacity-limited) and depends on task demands at each level. That is, if *perceptual load* (e.g., complexity of visual stimuli) is low, there is spare capacity for perceptual processing of goal-irrelevant information which allows it to enter awareness. But if perceptual load is high, capacity for perceptual processing of distractors is diminished, which reduces their interference in task performance. If *cognitive-control load* is high (e.g., performing a difficult concurrent working memory task), this reduces cognitive control resources available for goal-relevant processing and increases interference by distractors. Load theory suggests that task-interference by emotional distractors (e.g., task-irrelevant threat cues) may be increased by high cognitive-control load, and reduced by high perceptual load (although Lavie, 2005, p. 77, notes that distraction by salient stimuli is sometimes unaffected by high perceptual load; see also Vuilleumier, Armony, Driver, & Dolan, 2001). Evidence of effects of manipulating task demands on threat-distractor processing in anxiety is mixed (e.g., Bishop, 2007; Holmes et al., 2014; Okon-Singer, Lichtenstein-Vidne, & Cohen, 2013; Pourtois, Schettino, & Vuilleumier, 2013; Vytal, Cornwell, Arkin, & Grillon, 2012) and load theory has been criticised, e.g., for imprecise definition of perceptual load (Benoni & Tsal, 2013; Giesbrecht, Sy, Bundesen, & Kyllingsbaek, 2014). Nevertheless, the notion of competition for limited-capacity perceptual and cognitive-control processes (see also Desimone & Duncan, 1995) is influential in emotion processing research. For example, Pessoa's (2009) *dual-competition* model, based on a review of neuroscience evidence, proposes that emotion and motivation affect competition for both perceptual and cognitive control resources; with anxiety modulating processing of threat cues at each level of processing, mediated by amygdala-cortical interactions (see also reviews by Vuilleumier, 2005; Vuilleumier & Driver, 2007).

#### 3.6. Petersen and Posner's (2012) updated model of attention

Guided by their review of cognitive neuroscience research

findings, Petersen and Posner (2012) updated their 1990 attention model and identified five networks: an alerting network, two orienting networks and two executive control networks. The *alerting* system is involved in both transient alerting (reflected by faster response to a target when preceded by a warning cue) and sustained alerting (maintaining a general state of readiness). Alerting is linked with functioning of the locus coeruleus and noradrenaline system. The *orienting* system is no longer subdivided into separate subsystems for disengagement, shift and engagement, as more recent neuroscience data do not support that view (Posner & Fan, 2008). Instead, in line with Corbetta and Shulman's (2002) model, Petersen and Posner (2012) distinguish between *top-down orienting* which relates to a dorsal network and is involved in strategic control of attention, and *stimulus-driven orienting* which relates to a ventral network and to an interrupt response that allows reorienting to unattended salient stimuli.

The executive control system in Petersen and Posner's (2012) model extends the conscious detection function of their 1990 model to include other functions such as conflict and error detection and monitoring. Their updated model incorporates the proposal that the executive control system comprises two distinct brain networks: a frontoparietal control network involved in *transient moment-to-moment attention control*, i.e., rapid adaptive control in response to ongoing task demands; and a cingulo-opercular neural network which supports more enduring *maintenance of task sets* (Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008). However, the precise functions of the cingulo-opercular network, which includes the anterior insula and dorsal anterior cingulate cortex, are not fully agreed, with suggestions that it plays key roles in maintaining tonic alertness, memory retrieval, conflict and error monitoring, and switching between networks (Wallis, Stokes, Cousijn, Woolrich, & Nobre, 2015; Sadaghiani & D'Esposito, 2014; Menon, 2011; Sylvester et al., 2012).

#### 3.7. Unity-diversity model of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000)

A different view of executive control emerged from latent variable analyses of behavioural data from complex executive function tests, which indicated three separable functions (Friedman & Miyake, 2004; Miyake et al., 2000). (i) *Shifting* refers to switching between tasks or mental sets. Miyake et al. (2000, p. 56) point out that their construct of shifting is not synonymous with shifting of spatial attention, as different neural mechanisms are involved in task-switching and spatial orienting. (ii) *Updating* is a complex working memory function which involves monitoring and updating the contents of working memory for task-relevance, including deleting information which is no longer task-relevant, and adding new information which is task-relevant. (iii) *Inhibition* refers to inhibition of dominant or prepotent responses in Miyake et al.'s (2000) analysis (e.g., assessed on anti-saccade and Stroop tasks). Subsequent research by Friedman and Miyake (2004) examined two other inhibitory functions: distractor suppression (e.g., assessed on the flanker task); and resistance to interference from irrelevant intrusive memories, which is also referred to as cognitive inhibition (Diamond, 2013; Nigg, 2000). Data from healthy young adults suggest a general inhibition factor, which comprises distractor and response inhibition, which is distinct from resistance to intrusive memories (Friedman & Miyake, 2004). However, such findings may not necessarily generalise to other populations (Miyake et al., 2000), and deficits in distractor inhibition and response inhibition may be more separable in psychopathology and in children (Brydges, Anderson, Reid, & Fox, 2013; Diamond, 2013; Nigg, 2000).

Miyake et al. (2000) noted that correlations between shifting,

updating and inhibition measures indicate underlying commonality. This *unity* of executive functions may reflect a shared requirement of complex tasks to maintain goals in working memory and/or a common inhibitory process. In an update of their model, Miyake and Friedman (2012) propose that individual differences in executive functions are largely explained by three factors: a common executive function factor, and separate shifting-specific and updating-specific factors. According to the revised *unity-diversity* model, inhibition is subsumed under the common factor, so it may be a fundamental aspect of executive functions in general.

### 3.8. Diamond's (2013) framework of executive functions

Diamond (2013) broadens Miyake et al.'s (2000) model and, based on a review of empirical evidence, describes three core executive functions. (i) *Cognitive flexibility* includes set-shifting and task-switching from Miyake et al. (2000) and is also proposed to underlie ability to view events from different perspectives (which is also relevant to reason-based appraisal processes). (ii) *Working memory* relates to 'holding information in mind and working with it'. It is a broader construct than 'updating' and includes maintaining and manipulating representations of goal-relevant information in working memory. It also distinguishes between verbal and visuospatial working memory functions (Nee et al., 2012). (iii) *Inhibitory control* includes inhibition of selective attention (including distractor inhibition), inhibition of prepotent responses, and cognitive inhibition (inhibition of thoughts and memories).

Together these core functions support higher-level executive functions including reasoning, planning and problem solving. Diamond's (2013) review of executive functions provides a framework for guiding research in training to improve cognitive control. She advocates that, to enhance effectiveness (and maximise generalisation of and engagement with training), attention training should engage multiple executive control functions, and involve repeated practice of challenging tasks that increase incrementally in difficulty as training progresses.

### 3.9. Multiple demand system (Duncan, 2010)

The function of the *multiple demand system* described by Duncan (2010) overlaps with the construct of fluid intelligence and the common factor (i.e., unity) of executive functions (Miyake et al., 2000; Miyake & Friedman, 2012; Diamond, 2013). The multiple demand system comprises a network of prefrontal and parietal regions, which is activated by a diverse range of challenging cognitive tasks. This system coordinates the breakdown of goals for complex behaviours into subtasks which can then be solved by a series of mental programs. It thereby plays a key role in supporting goal-directed thought and action (for meta-analytic neuroimaging evidence of a common cognitive control network, see Niendam et al., 2012).

### 3.10. Individual differences in attention and cognitive control

There is considerable interest in individual differences in attention and cognitive control mechanisms, and how they link to environmental and biological factors. For example, individual differences in executive attention control are related to variables such as education experience and dopamine genes; and individual differences in alerting have been linked with function of the noradrenaline neurotransmitter system (Petersen & Posner, 2012; Posner & Fan, 2008; Posner & Rothbart, 2005).

As noted earlier, individual differences in attention control may contribute to anxiety vulnerability, as poor attention control has been linked with increased risk of anxiety disorders (Derryberry &

Rothbart, 1997; Lonigan et al., 2004; see Section 2.7). Furthermore, Sylvester et al. (2012) propose that both high trait anxiety and anxiety disorders are associated with individual differences in dysfunction in four brain networks: ventral attention, frontoparietal, cingulo-opercular and default mode network; which results in increased bottom-up stimulus-driven attention, reduced top-down attention control, increased error sensitivity, and poor emotion regulation, respectively. The default mode network is an interconnected brain system that is active during rest and self-focused cognitive activity (Buckner, Andrews-Hanna, & Schachter, 2008). Sylvester et al. (2012) propose that anxiety-related dysfunction in each of the four networks should be evident on tasks using neutral stimuli (i.e., it is not specific to processing threat information). Moreover, training which improves network functioning may contribute to treatment for anxiety. For example, training individuals to ignore non-emotional task-irrelevant stimuli may enhance frontoparietal network function and attention control, and thereby help reduce anxiety.

Research into anxiety-related impairment in executive functions is relatively limited (for reviews, see Berggren & Derakshan, 2013; Snyder et al., 2015). Several studies indicate that anxiety is associated with impaired inhibitory control, including poor inhibition of distractors and prepotent responses on flanker and antisaccade tasks (Berggren & Derakshan, 2013; Eysenck & Derakshan, 2011; Mogg et al., 2015). Although findings are mixed, other research suggests that anxiety impairs cognitive flexibility (e.g., indexed by task-switching) and working memory functions, which may be modulated by task demands or presence of threat (Berggren & Derakshan, 2013; Snyder et al., 2015; Stout et al., 2013; 2015).

Snyder et al.'s (2015) review illustrates how executive function deficits are associated with a wide range of psychopathology. For example, a recent meta-analysis indicates that clinical depression is associated with impairment across multiple executive functions, including inhibitory control, shifting, and updating working memory (Snyder, 2013). Severity of executive deficits may vary across different disorders; for example, impaired updating of working memory may relate more closely to depression than anxiety (Yoon, LeMoult, & Joormann, 2014). Moreover, studies of self-reported attention control in healthy young adults suggest that poor cognitive flexibility relates more closely to depression than anxiety symptoms; whereas poor top-down inhibitory control (e.g., high general distractibility) may relate more closely to anxiety than depression symptoms (Olafsson et al., 2011; Reinholdt-Dunne, Mogg, & Bradley, 2013). Also, impairment in top-down inhibitory control (indexed by the interference effect of neutral distractors on a flanker task) may vary across anxiety disorders, with less impairment in specific phobias than other anxiety disorders (Mogg et al., 2015). Further research using performance-based measures in clinical and non-clinical samples is required to clarify the extent to which anxiety and depression symptoms are associated with impairment not only in a common cognitive control system (Duncan, 2010; Miyake et al., 2000), but also in specific functions such as inhibitory control, cognitive flexibility and working memory. Thus, it would seem useful, wherever possible, for studies which examine the relationship between anxiety and threat processing to also include assessment of the relationship between anxiety and efficiency of processing neutral information on the same task.

## 4. Integrative framework

This section proposes a framework describing cognitive mechanisms contributing to anxiety and anxiety-related ABs to threat. It also considers task-related, individual-difference and situational

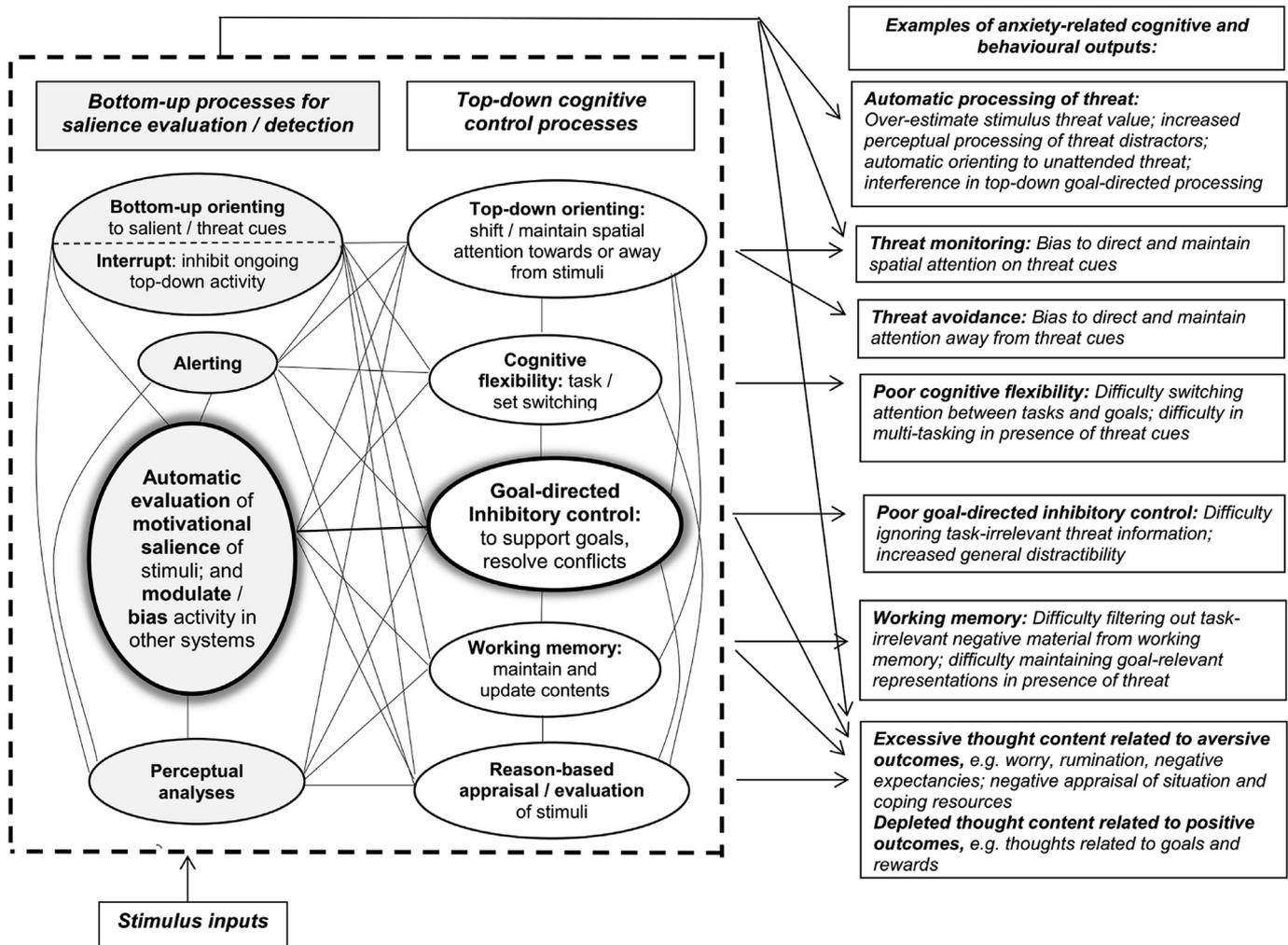


Fig. 4. Integrative framework of bottom-up and top-down cognitive functions in anxiety.

variables which influence ABs to threat, which require explanation by cognitive models of anxiety. Clarifying the mechanisms and variables that influence anxiety-related ABs to threat is relevant to ABM training which aims to modify AB.

First, we explain the choice of components of the framework (Section 4.1; Fig. 4), which is guided by evidence-based models of attention and executive control (Section 3; Fig. 3a, b) and bottom-up salience-evaluation processes (Section 4.3.1). Second, we note cognitive correlates of anxiety relating to core functions of the framework (Section 4.2). Third, we discuss mechanisms contributing to anxiety: bottom-up stimulus-salience evaluation (Section 4.3.1), bottom-up and top-down attention orienting (Section 4.3.2) and other top-down cognitive control processes (Section 4.3.3). We consider how these mechanisms and other variables influence ABs in orienting to threat (Section 4.4); whether variation in anxiety-related ABs relates to their motivational/goal-related roles (Section 4.5); and whether individual differences in AB in orienting to threat predict treatment outcome in anxiety (Section 4.6). Implications of the framework for ABM training are considered later (Section 5).

#### 4.1. Core components of framework

The preceding overview indicates that there is no clear consensus regarding the organisation of attention and executive

control functions (Section 3; Fig. 3a). Nevertheless, models of attention and cognitive control share key ideas about several core functions (Fig. 3b) which have been integrated into the framework outlined in Fig. 4. This section explains the thinking behind the choice of its components.

Bottom-up processes influence attention to and evaluation of motivationally salient stimuli. In relation to attention, these include *alerting* (Petersen & Posner, 2012), *automatic orienting* to salient stimuli, *interruption* of ongoing task-related activity (Corbetta & Shulman, 2002; Petersen & Posner, 2012), and selection of information in early *perceptual processes* (Desimone & Duncan, 1995; Lavie, 2005). Automatic orienting and interrupt functions are linked in Fig. 4, as they have both been related to an underlying ‘circuit-breaker’ mechanism (Corbetta & Shulman, 2002, p. 201). However, they can also function independently, as the automatic interrupt function contributes to anxiety-related threat-distractor interference in the absence of orienting (e.g., on modified Stroop task, Algom et al., 2004). Another bottom-up process, which plays a crucial role in anxiety, is *automatic evaluation* of the affective and motivational significance of stimuli (Pessoa & Adolphs, 2010; Pessoa, 2009; Vuilleumier & Driver, 2007; Vuilleumier, 2005); the functions of which are discussed later (Section 4.3.1).

The top-down cognitive-control system supports goal-directed thought and action, and biases bottom-up processes in favour of information relevant to current tasks and concerns (Corbetta &

Shulman, 2002; Desimone & Duncan, 1995; Duncan, 2010; Miyake & Friedman, 2012; Miyake et al., 2000). While some models fractionate this into frontoparietal and cingulo-opercular networks supporting moment-to-moment control and stable set-maintenance, respectively (Dosenbach et al., 2008; Petersen & Posner, 2012), the precise functions of these brain networks are subject to debate (Wallis et al., 2015; Sadaghiani & D'Esposito, 2014; Menon, 2011). Hence, the framework draws on models of cognitive control that are based largely on behavioural (rather than neuroimaging) data to identify core top-down functions.

Latent variable analyses of behavioural data from executive function tests indicate key functions of *goal-directed inhibitory control* (distractor, response and cognitive inhibition), *cognitive flexibility* (set-shifting, task-switching), and *working memory* (maintaining and updating representations of goals, external stimuli and internal thought content) (Diamond, 2013; Friedman & Miyake, 2004; Miyake et al., 2000). These functions are inter-related and contribute to a *unitary construct of cognitive control* (Duncan, 2010; Miyake & Friedman, 2012; Miyake et al., 2000). Inhibitory control is a shared feature of top-down processes and may be subsumed under a common cognitive control factor (Miyake & Friedman, 2012). Notwithstanding its commonality across top-down functions, goal-directed inhibitory control is included separately in the framework, given its role in resolving processing conflicts between task-relevant and irrelevant information, and its distinction from spatial orienting.

A limitation of these latent variable analyses is that findings were based on a restricted sample of tests of complex executive functions, which did not include visuospatial attention tasks. Nevertheless, *top-down orienting* is included in the framework as it relates to two different types of AB in anxiety: maintenance of attention on threat, and threat avoidance (Cisler & Koster, 2010), and is not the same as goal-directed inhibitory control. The distinction between top-down and bottom-up orienting is guided by recent models of attention (Corbetta & Shulman, 2002; Petersen & Posner, 2012), rather than the earlier spotlight model of attention which proposed separate orienting mechanisms of shift, engagement and disengagement, each with distinct neural correlates (Posner & Petersen, 1990), as the latter view is no longer supported by neuroscience findings (Posner & Fan, 2008).

Another top-down process is *strategic reason-based appraisal*, which corresponds to secondary appraisal (or reappraisal) in Beck and Clark (1997), and guided threat evaluation in Bar-Haim et al. (2007). Reasoning is a higher-level executive function, which engages lower-level functions such as goal-directed inhibitory control, cognitive flexibility and working memory (Diamond, 2013), and supports re-evaluation of the emotional and motivational significance of threat cues while taking account of wider sources of information including situational context, learning experiences and knowledge of coping resources.

#### 4.2. Cognitive correlates of anxiety

Anxiety may be associated with various perturbations in threat processing which relate to the core functions of the framework in Fig. 4, such as (i) dysfunction of automatic bottom-up stimulus-salience evaluation processes, resulting in over-estimation of the threat value of ambiguous or mildly aversive cues, and a dominant modulatory influence on other processes to prioritise threat information, (ii) enhanced perceptual processing of task-irrelevant threat cues, (iii) increased alerting by threat cues, (iv) enhanced automatic spatial orienting towards threat, (v) increased automatic interruption of task performance by threat distractors, (vi) biases in top-down spatial orienting towards and away from threat, including strategic searching for and holding attention on threat,

and threat avoidance, (vii) poor top-down inhibition of processing task-irrelevant threat, (viii) reduced cognitive flexibility particularly in the presence of threat, (ix) difficulty filtering out task-irrelevant threat information from working memory, and (x) biased strategic elaborative reappraisal of threat cues.

The framework not only provides a context for examining threat processing in anxiety, but also for assessing its relationship with baseline efficiency of each function, indexed by performance on tasks using neutral, non-emotional information. For example, an anxiety-related deficit in inhibiting processing of threat distractors may relate to a general deficit in inhibiting task-irrelevant information, i.e., general distractibility (Eysenck et al., 2007). The same may apply to other functions, such as cognitive flexibility, or bottom-up spatial orienting (Eysenck et al., 2007; Sylvester et al., 2012).

#### 4.3. Cognitive mechanisms contributing to anxiety

Within this framework, bottom-up and top-down systems exert mutual influences on each other to determine whether thoughts and actions are engaged on adaptive goals, or on processing threat information which is unrelated to current goals and which may potentially pose danger for the individual. Chronic and/or excessive anxiety may stem from imbalance among reciprocal influences between bottom-up and top-down systems, resulting in dominance of a threat-focused motivational mode (to detect, evaluate and respond to potential threat cues) over an adaptive, task-oriented, positively focused goal-engagement mode. The outcome of competition between these two modes biases and co-ordinates bottom-up and top-down processes involved in stimulus-evaluation, attention, working memory and reasoning.

While anxiety may be correlated with a wide variety of perturbations in threat processing (see Fig. 4 for examples), not all are implicated in its onset and maintenance. Previous models of anxiety suggest that anxiety vulnerability and its maintenance, and ABs to threat, may stem from dysfunction in one or more cognitive functions, including automatic evaluation of the threat value of stimuli; automatic and strategic attention orienting to threat; and other cognitive control processes supported by top-down inhibitory control, which oppose bottom-up processing of threat. These functions are considered in the following subsections.

##### 4.3.1. Bottom-up stimulus-salience evaluation processes

Bottom-up stimulus-evaluation processes influence the extent to which minor threat cues are identified as having high or low aversive motivational salience. From a neuroscience perspective, one dominant view is that subcortical brain regions are responsible for nonconscious evaluation of stimulus threat value. These include the amygdala and pulvinar, which are widely regarded as primitive brain structures in evolutionary terms. This bottom-up mechanism may allow rapid automatic analysis of and response to threat cues, independent of conscious processing in cortical regions (LeDoux, 1996).

A more recent view, put forward by Pessoa and Adolphs (2010), is that the primary role of the amygdala is to coordinate and modulate functioning of cortical networks during the evaluation of the biological or motivational significance of stimuli. They conclude from their review of neuroscience research that cortical regions are involved in both conscious and nonconscious processing of emotional information; and these multiple parallel sources of information are automatically integrated in subcortical regions, such as the amygdala and pulvinar. The amygdala consequently biases the allocation of processing resources to stimuli by modulating other brain networks in order to prioritise selection of motivationally salient information (Pessoa & Adolphs, 2010).

The amygdala is involved not only in automatic processing of threat-related information, but also in processing emotionally salient information more generally (Sergerie, Chochol, & Armony, 2008). The amygdala is well-placed for this role given its extensive connectivity with subcortical and cortical networks involved in perceptual processing, attention, cognitive control and emotional arousal (Davis & Whalen, 2001; Pessoa, 2009).

Moreover, its activity is modulated by cognitive control processes, including inhibitory control and reason-based appraisal (Buhle et al., 2014; Cohen et al., 2015; Iordan, Dolcos, & Dolcos, 2013; Kanske, Heissler, Schonfelder, Bongers, & Wessa, 2010; Kohn et al., 2014; McRae et al., 2010; Ochsner & Gross, 2005; Phan et al., 2005). For example, amygdala response to emotional stimuli is reduced by both attention control (focusing on a primary task rather than emotional distractors) and reappraisal (reinterpreting the meaning of emotional stimuli), which are supported by a common neural network in frontoparietal regions shared by cognitive control processes (Kanske et al., 2010).

This research is complemented by extensive neuroimaging evidence indicating that anxiety disorders are associated with dysfunction in a network of subcortical and cortical structures (*fear circuit*), which includes the amygdala and prefrontal cortex (e.g., Monk et al., 2008; see reviews by Taylor & Whalen, 2015; Shin & Liberzon, 2010). Anxiety disorders are characterised by heightened amygdala response to threat cues, and dysfunctional connectivity between the amygdala and prefrontal cortical regions which support cognitive control and emotion regulation. This fear circuit is involved in evaluation and detection of threat cues, eliciting and regulating emotional responses, and fear learning and extinction (LeDoux, 2012).

Thus, the present framework encompasses the view that bottom-up stimulus-salience evaluation processes play an important role in contributing to anxiety, and that evaluation of the motivational importance of a stimulus, which includes its threat value, can occur outside awareness and depends on automatic integration of information from multiple sources (Pessoa & Adolphs, 2010). The key role of this stimulus-salience evaluation mechanism is not only to identify whether an unattended stimulus has high motivational salience for the individual, but also to modulate processing in other bottom-up and top-down systems in favour of prioritising motivationally important stimuli. This includes activating bottom-up attention functions of reflexive orienting to threat, interruption of goal-directed processing, alerting; modulating perceptual processing; and biasing top-down processes such as controlled spatial orienting, working memory and reasoning in favour of processing motivationally salient stimuli. Importantly, despite largely operating automatically, reactivity of this stimulus-salience-evaluation mechanism to threat cues can be downregulated by top-down cognitive control (Bar-Haim et al., 2007; Cohen et al., 2015; Iordan et al., 2013; Ochsner & Gross, 2005).

Anxiety-proneness and anxiety disorders may reflect malfunction in more than one operation of this mechanism, including (i) exaggerated automatic evaluation of the threat value of stimuli, (ii) excessive outputs to other bottom-up and top-down processes, and (iii) inadequate modulation of its activity by inputs from top-down cognitive-control processes. Consequently, it may exert a dominating modulatory influence over bottom-up and top-down processes, with resultant difficulty in sustaining adaptive goal-directed thought and action in the presence of minor threat cues.

#### 4.3.2. Bottom-up and top-down attention orienting

The role of bottom-up attention orienting processes in anxiety has been the subject of debate in previous models of anxiety. A key question of relevance to ABM research is whether or not biased

automatic orienting to threat plays a causal role in anxiety. One view is that enhanced automatic initial orienting towards minor threat cues underlies proneness to anxiety, and that attentional avoidance of threat is associated with resilience to anxiety, i.e. low trait anxiety (Williams et al., 1988, 1997). Hence, reducing AB to threat may reduce anxiety (see also Mathews & MacLeod, 2002). Another view is that anxious individuals show increased automatic initial orienting to minor threats because the stimuli have been evaluated as having disproportionately high threat value, due to a bias in automatic threat-evaluation processes (Mogg & Bradley, 1998).

The present framework is more consistent with the latter view and extends it. Both anxiety and ABs in orienting to threat may be the *consequence* of imbalance between bottom-up threat-salience-evaluation and top-down cognitive-control systems. While AB in initial attention orienting towards threat may not be the primary cause of anxiety; this and other ABs may contribute to it, as noted by previous models of anxiety. For example, AB in automatic initial orienting to threat may increase detection of minor threat cues in the environment, AB in strategic maintenance of attention on threat may enhance dwelling on danger, AB in strategic threat avoidance or unstable AB may impede habituation during threat exposure (e.g., Fox et al., 2001; Mogg & Bradley, 1998; Williams et al., 1988). These ABs in orienting towards and away from threat complement AB in threat-distractor interference, which also reflects imbalance between bottom-up and top-down systems, and may also contribute to anxiety (e.g., difficulty in suppressing AB in threat-distractor interference, due to enhanced bottom-up interrupt and insufficient task-related cognitive control, may increase intrusive negative thoughts and worries). Thus, in our framework, anxiety and ABs are manifestations of imbalance between bottom-up salience-evaluation and top-down cognitive-control systems.

Much evidence of anxiety-related ABs in spatial orienting to threat has come from visual-probe task and eye-tracking studies (Armstrong & Olatunji, 2012; Bar-Haim et al., 2007). These tasks typically use relatively long stimulus-exposure durations for threat cues (e.g., 500 ms or more) which allows influences of both automatic and strategic orienting. Some visual-probe studies, which use masked and briefly presented (e.g., 14–20 ms) stimuli to restrict awareness, indicate an anxiety-related bias in automatic initial orienting towards threat (Bar-Haim et al., 2007; Fox, 2002; Mogg, Bradley, & Williams, 1995). However, this research does not clarify whether this bias is a correlate or cause of anxiety.

It has been argued that if ABM-threat-avoidance training is effective in reducing both AB towards threat and anxiety, this would confirm a causal role of the AB in anxiety (MacLeod & Clarke, 2015). The weak effect of ABM-threat-avoidance training on reducing anxiety could be explained by this ABM method being insufficiently effective in modifying the mechanisms responsible for both AB and anxiety. If so, its poor efficacy would not necessarily challenge the hypothesis of a causal role of AB in anxiety.

However, if ABM is shown to be effective in reducing both anxiety and an AB in orienting towards threat, this would not necessarily confirm that this particular AB causes anxiety, because ABM may affect other mechanisms which underlie both AB in orienting to threat and anxiety. For example, repeatedly ignoring minor threat cues may strengthen top-down inhibitory control processes which oppose the influence of the bottom-up stimulus-salience evaluation system, which prioritises threat processing and biases bottom-up and top-down orienting (Fig. 4). Thus, modification of the relationship between top-down cognitive control and bottom-up threat-salience evaluation may result in reductions in both anxiety and ABs in orienting responses to threat.

Also, some evidence suggests that ABM-threat-avoidance training may modify strategic rather than automatic orienting

towards threat (Koster, Baert, Bockstaele, & De Raedt, 2010). Thus, even if a strong effect were to be found of ABM-threat-avoidance training on both AB towards threat and anxiety, this would not necessarily confirm the hypothesis that a bias in automatic initial orienting towards threat has a causal role in anxiety. This highlights the importance of clarifying the specific processes involved in ABs, as this has implications for ABM regarding which AB should be targeted (e.g., automatic orienting, strategic orienting, goal-directed inhibitory control of threat distractors). Further research should investigate mechanisms mediating the effects of ABM on both anxiety and ABs, including the extent to which cognitive control processes may contribute to each effect (Browning, Holmes, Murphy, Goodwin, & Harmer, 2010; Heeren, Mogoşşe, McNally, et al., 2015).

#### 4.3.3. Cognitive control processes

A common theme of models of anxiety concerns the role of top-down cognitive control in supporting goal-directed processes and opposing processing of task-irrelevant threat (e.g., Bar-Haim et al., 2007; Derryberry & Rothbart, 1997; Eysenck et al., 2007; Lonigan et al., 2004; Mathews & Mackintosh, 1998; Rothbart et al., 1994; Williams et al., 1996; 1997). Top-down cognitive control may play a protective role in regulating emotion and reducing anxiety-proneness (Derryberry & Rothbart, 1997; Lonigan et al., 2004; Rothbart et al., 1994). It has also been described as an override mechanism that opposes the influence of the automatic threat-evaluation system on attention (Bar-Haim et al., 2007).

Within the present framework, this override mechanism may reflect co-ordinated functioning of multiple top-down cognitive control processes, involving a common executive function factor (Miyake & Friedman, 2012) or multiple demand system (Duncan, 2010), which supports adaptive goal-directed processing. Thus, depending on the specific task requirements and motivational priorities of the individual, an override mechanism may engage a wide range of top-down functions (Fig. 4), including goal-directed inhibitory control (e.g., suppress bottom-up threat-salience evaluation system and resolve processing conflicts to support goal-directed activity), controlled spatial orienting (e.g., hold attention on goal-relevant information), attention flexibility (adaptive switching between tasks to support goals), working memory operations (maintaining representations of goals in working-memory and updating its contents), and reason-based appraisal processes (e.g., re-evaluate the importance of task-irrelevant threat cues). Of these functions, goal-directed inhibitory control may be particularly important in opposing processing of task-irrelevant threat information (Eysenck et al., 2007), as well as contributing to top-down cognitive control functions in general (Miyake & Friedman, 2012).

While a key feature of this framework is the widely-used construct of inhibitory control (Diamond, 2013; Miyake & Friedman, 2012), its role in various aspects of processing such as attention and memory requires further clarification (Aron, Robbins, & Poldrack, 2014). It is helpful to distinguish between bottom-up (automatic) and top-down sources of inhibition (Aron et al., 2014), which together influence the extent to which task-irrelevant threat cues influence task performance. For example, slower colour-naming of threat than neutral words on the modified Stroop task (or slower detection of neutral targets among threat than neutral distractors on visual-search tasks) may reflect a combination of automatic inhibition (interruption) of task-related processes by the threat-salience evaluation system, and insufficient goal-directed inhibitory control to oppose this bottom-up effect.

Poor goal-directed inhibitory control may not only be an important mechanism contributing to ABs in anxiety, but it may

also play a key role in intrusive negative thinking including rumination and worry (Kircanski, Johnson, Mateen, Bjork, & Gotlib, 2015). Efficient goal-directed inhibitory control also supports reason-based appraisal, which involves inhibition of negative information or meanings of stimuli, in favour of positive or nonthreat meanings (Cohen, Daches, Mor, & Henik, 2014; McRae et al., 2010; Kankse et al., 2010; Tabibnia et al., 2011). Interventions which strengthen goal-directed inhibitory control, such as training individuals to ignore neutral task-irrelevant information on a flanker task, may be effective in reducing intrusive negative thinking and mood (Cohen, Mor, & Henik, 2014) and in suppressing neural activity such as amygdala function associated with bottom-up threat bias on processing (Cohen et al., 2015).

Given that the cognitive control system operates in a unified co-ordinated manner to support goal-directed thought and behaviour (Corbetta & Shulman, 2002; Duncan, 2010; Miller & Cohen, 2001), an effective override mechanism may depend more on synchronised functioning of the cognitive control system as a whole, rather than the function of any isolated component. If so, ABM training methods which engage a wide range of top-down processes in order to enhance co-ordinated cognitive control (particularly, goal-directed inhibitory control) and oppose bottom-up threat processing, may be more effective in the treatment of anxiety, than ABM methods which focus on modifying one specific cognitive function such as automatic spatial orienting towards threat.

#### 4.4. Mechanisms and variables influencing ABs in orienting to threat

This section considers how ABs assessed on spatial attention tasks are influenced by mechanisms identified in the framework (Section 4.4.1), and by other task-related, individual-difference and situational variables; such as the time-course of ABs (which relates to the exposure duration of threat cues; Section 4.4.2), the symptom profile of anxious individuals (Section 4.4.3), external stressors (Section 4.4.4), trait attention control (Section 4.4.5), and temporal instability of ABs (Section 4.4.6). It is important to clarify the mechanisms and variables which influence ABs in orienting to threat, because they not only require explanation by models of anxiety, but also have implications for ABM training methods (e.g., ABM-threat-avoidance-training which uses spatial attention tasks to reduce AB in orienting towards threat). Other experimental variables that may influence ABs are also briefly noted (Section 4.4.7).

##### 4.4.1. Mechanisms underlying ABs on spatial attention tasks

In an extensive review of empirical evidence of ABs in anxiety, Van Bockstaele et al. (2014) concluded that, when recent studies were taken into account, the strength of the relationship between AB and anxiety seems less consistent than suggested by an earlier meta-analysis (Bar-Haim et al., 2007). Hence, one purpose in advancing the present framework is to help identify variables that may explain why some anxious individuals show an AB towards threat, and others show no bias or threat-avoidance. Consequently, it is helpful to consider differing manifestations of ABs on spatial attention tasks and the mechanisms which may contribute to them. This is relevant to ABM studies, which have used several different tasks to assess and modify AB (e.g., visual-probe, spatial-cueing, visual-search tasks); so it is informative to examine whether these different tasks reflect similar underlying processes.

Before doing so, it is useful to clarify the terminology used to describe different ABs. As noted earlier (Section 2.13), ABs observed on spatial attention tasks include *initial orienting towards threat*, *maintaining attention on threat*, and *avoidance of threat*. The AB index of *threat-distractor interference* is more commonly inferred

from tasks that do not involve spatial orienting (e.g., modified Stroop task). The present framework uses the term, *maintaining attention*, in preference to *delayed disengagement*. While these terms are often used interchangeably (e.g., Fox et al., 2001), the term disengagement has also been defined in different ways. According to Posner and Petersen's (1990) influential spotlight model of attention, disengagement refers to one specific component of visual orienting, distinct from shifting and engagement, with its own neural substrate (parietal cortex). Disengagement difficulty has also been defined as an AB component reflecting increased dwelling on threat, which may facilitate its more elaborative processing (Fox et al., 2001). It also refers to capture of attention by threat and difficulty redirecting attention to a new stimulus, related to poor attention control mediated by the prefrontal cortex (Cisler & Koster, 2010). This seems to imply both sustained engagement of attention on threat and delayed disengagement. Thus, it seems preferable to describe it as maintained attention (or holding attention, or dwelling) on threat, as this avoids implying one underlying mechanism and confusion with the pre-existing definition of disengagement as one of three components of spatial orienting (Posner & Petersen 1990). Another advantage is that recent models of attention no longer uphold the distinction between separate shifting, engagement and disengagement components of orienting (Posner & Fan, 2008) and distinguish between bottom-up and top-down influences on orienting (Corbetta & Shulman, 2002; Petersen & Posner, 2012).

According to the framework outlined in Fig. 4, ABs to threat are influenced by both bottom-up and top-down processes. This view integrates ideas from early models which focused on the role of each type of process in ABs (e.g., Williams et al., 1988; Wells & Matthews, 1994) and later views of the contributions of both processes to ABs (e.g., Bar-Haim et al., 2007; Beck & Clark, 1997; Cisler & Koster, 2010; Derryberry & Rothbart, 1997; Eysenck et al., 2007; Lonigan et al., 2004; Mogg & Bradley, 1998; Williams et al., 1997).

Specific mechanisms, which may influence RT-based measures of AB on spatial attention tasks, include bottom-up threat-salience evaluation (which biases other processes including orienting), automatic interruption (inhibition) of ongoing activity, alerting, automatic orienting to threat, strategic orienting towards or away from threat, goal-directed inhibitory control (which opposes the biasing effect of the bottom-up salience-evaluation mechanism, and supports task-related processing and threat-distractor inhibition), and switching from bottom-up threat processing to top-down goal-directed processing; see Fig. 4. While automatic orienting and interrupt functions may relate to a common circuit-breaker mechanism (Corbetta & Shulman, 2002), they are also separable, as threat cues may automatically interrupt performance on tasks independent of spatial orienting (e.g., modified Stroop task using masked and unmasked threat stimuli; Algom et al., 2004). The interrupt function contributes to a slowing effect of threat on task performance, while alerting contributes to a speeding effect of threat on RT. These may influence AB indices which are based on a comparison of RTs from trials where threat is present versus absent.

Consequently, some AB measures from attention-orienting tasks, which are based on comparison of *threat-present versus threat-absent* trials, may reflect processes other than AB in orienting to threat. For example, on emotional spatial-cueing tasks, slower RTs on invalid-threat versus invalid-nonthreat cue trials may reflect maintained spatial attention on the location of threat to facilitate its identification (Fox et al., 2001), poor attention control (Cisler & Koster, 2010; Eysenck et al., 2007), and/or automatic interruption of task performance triggered by threat which does not involve spatial orienting (Mogg, Holmes, Garner, & Bradley, 2008); while faster RTs on invalid-threat versus invalid-nonthreat cue trials may reflect a spatial attention bias away from threat

suggesting avoidance (Yiend et al., 2015) and/or bottom-up alerting triggered by threat which speeds RT.

Relatedly, some studies using the visual-probe task (including some ABM studies) use a nonstandard index of AB, which compares RTs to probes replacing neutral cues on threat-neutral cue trials (i.e., threat-incongruent trials) versus RTs to probes on trials with neutral-neutral cues. As these trial conditions differ in presence versus absence of task-irrelevant threat, slower RTs on threat-incongruent (relative to neutral-neutral) trials may reflect greater maintenance of spatial attention on threat, poor top-down threat-distractor inhibition, and/or enhanced bottom-up interrupt by threat which may slow RT. Hence, this index may not necessarily indicate maintained spatial attention on threat (or delayed disengagement) (e.g., Carlbring et al., 2012; Koster, Crombez, Verschuere, & De Houwer, 2004; Mogg et al., 2008).

On the visual-search task, slower RTs to detect nonthreat targets amongst threat distractors (relative to nonthreat targets amongst nonthreat distractors) may also reflect multiple processes. These may include initial orienting to threat distractors and maintaining attention on them (due to bias from the bottom-up threat-salience evaluation mechanism on automatic and strategic orienting), automatic interruption/inhibition of task-related processes (activated by the bottom-up threat-salience evaluation mechanism in response to threat), and insufficient inhibitory control to oppose bottom-up bias and support threat-distractor inhibition and task-related processes. Thus, ABM training which uses the visual-search task, such as ABM-positive-search training, may influence multiple component processes (see Section 5.4).

These examples illustrate difficulties in inferring a specific bias in spatial orienting of attention, such as maintaining attention on threat, from AB indices which compare RTs between threat-present and threat-absent trials (e.g., emotional spatial-cueing, visual-search tasks). However, on the visual-probe task, the widely-used conventional index of AB compares RTs to probes in the opposite versus same location as threat cues, on trials presenting threat-neutral stimulus-pairs (Fig. 1, upper panel). As a threat cue is displayed on both trial types, any general slowing or speeding effects on RT (due to interrupt or alerting responses triggered by presence of threat) may be similar across both conditions. Hence, the AB index is presumed to provide a snapshot of the allocation of spatial orienting of attention to threat (i.e., whether spatial attention was focused on the spatial location of the threat or nonthreat stimulus, at the offset of the stimulus-pair and onset of probe). Thus, the conventional index of AB assessed at short stimulus durations (within 500 ms of stimulus onset) is widely held to reflect a bias in initial orienting of spatial attention to threat (MacLeod et al., 1986; Williams et al., 1988, 1997). The most commonly used stimulus duration on the visual-probe task is 500 ms (which is often used in ABM studies to both modify and assess AB). This duration is long enough to allow awareness of the stimuli and influences of both bottom-up and top-down processes on orienting. Hence, the AB index assessed at 500 ms cannot be assumed to solely reflect automatic bottom-up attention orienting.

The conventional AB index on the visual-probe task does not distinguish between shift, engage and disengage components of initial orienting based on Posner and Petersen's (1990) original model of attention (Cisler & Koster, 2010; Fox et al., 2001). Instead, by manipulating the exposure duration of the threat-neutral stimulus pairs, this AB index has been used to examine other aspects of ABs such as initial orienting, maintained attention and threat avoidance, which may reflect differing bottom-up and top-down influences on orienting (Corbetta & Shulman, 2002; Petersen & Posner, 2012; for further discussion see Section 4.4.2).

The framework distinguishes between attention orienting and inhibitory processes (Fig. 4). While the functions of attention

orienting and inhibitory processes may overlap (e.g., goal-directed inhibitory control may contribute to various cognitive control functions, including strategic orienting), they are not synonymous, so it is helpful to consider their differing influences on AB tasks. For example, their distinction may help explain the lack of correlation between AB indices from the visual-probe and modified Stroop tasks (Cisler et al., 2009; Dalgleish et al., 2003; Mogg, Bradley et al., 2000), which engage spatial orienting and inhibitory processes to differing degrees. Attention orienting and inhibitory processes may reflect differing motivational influences; e.g., automatic initial orienting to threat and automatic inhibition of task-related processes to facilitate detection of danger; holding spatial attention on threat cues to facilitate more extensive evaluation of them; strategic orienting of attention away from threat and effortfully inhibiting processing of threat-distractors to reduce distress and/or support task-related processing. Distinguishing between orienting and inhibitory processes may also help explain why some ABM methods may be more effective than others; as ABM-threat-avoidance and ABM-positive-search training may engage spatial orienting and goal-directed inhibitory control processes to differing degrees, discussed later (Section 5).

#### 4.4.2. Time-course of ABs in orienting: initial orienting, maintained attention, threat avoidance

Most prior cognitive models of anxiety predict an automatic bias in initial orienting of attention towards threat in anxiety (e.g., Bar-Haim et al., 2007; Cisler & Koster, 2010; Lonigan et al., 2004; Mogg & Bradley, 1998; Williams et al., 1988, 1997). However, these models vary in predictions regarding the subsequent time-course of ABs to threat. For example, they propose that anxious individuals maintain attention on threat (Fox et al., 2001), may sometimes suppress AB to threat via task-related effort (Williams et al., 1997), may sometimes show threat avoidance following initial orienting to threat via distress-reduction strategies (Mogg & Bradley, 1998), or may show threat avoidance following initial orienting to threat and briefly holding attention on threat (Cisler & Koster, 2010).

The time-course of ABs has been examined on the visual-probe task by manipulating the exposure duration of the threat-neutral stimulus-pairs (e.g., between 14 ms and 2000 ms). The AB index assessed at shorter stimulus durations may be more sensitive to bottom-up bias in initial orienting to threat, compared with AB assessed at longer stimulus durations, which allow greater opportunity for strategic top-down influences to sustain or oppose bottom-up bias. Evidence of enhanced automatic initial attention to threat in anxiety includes findings from visual-probe and modified Stroop tasks of ABs for threat words presented very briefly (e.g., 14 ms) and masked to restrict awareness of word content (e.g., Fox, 2002; Mogg et al., 1995; Mogg, Bradley, Williams, & Mathews, 1993). Recent reviews conclude that, despite some inconsistencies, overall evidence supports automatic ABs to threat in anxiety (Bar-Haim et al., 2007; Teachman et al., 2012).

However, in most visual-probe-task studies, awareness of threat is not restricted, which allows ABs to be influenced by both automatic and controlled processes. Such studies often show anxiety-related AB for threat, but not always (see meta-analysis by Bar-Haim et al., 2007), and more recent reviews remarked on the variable findings of ABs in anxious adults (Van Bockstaele et al., 2014) and children (Dudeny, Sharpe, & Hunt, 2015). Research findings commonly (but not always) indicate an AB towards threat cues in anxious adults at shorter stimulus durations ( $\leq 500$  ms; Bar-Haim et al., 2007), whereas the fewer findings at longer durations (e.g., 1000–2000 ms) appear more variable, and include maintained attention on threat, no bias, or threat avoidance (e.g., Bar-Haim et al., 2010; Bradley, Mogg, Falla, & Hamilton, 1998; Bradley, Mogg, White, Groom, & de Bono, 1999; Dalgleish et al., 2003;

Koster, Verschuere, Crombez, & Van Damme, 2005; Mogg & Bradley, 2006; Mogg, Bradley, de Bono, & Painter, 1997; Mogg, Bradley, Miles, & Dixon, 2004; Mogg, Philippot, & Bradley, 2004). Avoidance or attenuated AB to threat at longer stimulus durations seem more likely to be associated with high threat or phobia-related stimuli, or high stress (e.g., Bar-Haim et al., 2010; Koster et al., 2005; Mogg & Bradley, 2006; Mogg, Bradley et al., 2004; Mogg, Philippot et al., 2004; Wald et al., 2011; see also Section 4.4.4 on stressors).

Eye-tracking is also used to assess the time-course of biases in spatial orienting (e.g., direction and duration of gaze on threat versus nonthreat cues). Meta-analytic findings from free-viewing studies indicate a bias in initial orienting towards threat, but not in maintenance of gaze on threat in anxiety (Armstrong & Olatunji, 2012). Several studies indicate attenuated AB, or threat avoidance, following initial threat vigilance (e.g., Calvo & Avero, 2005; Garner, Mogg, & Bradley, 2006; Hermans, Vansteenwegen, & Eelen, 1999; In-Albon, Kossowsky, & Schneider, 2010; Pflugshaupt et al., 2005; Rinck & Becker, 2006). However, eye-tracking does not directly assess covert spatial attention and commonly examines ABs over relatively long time periods (e.g., several seconds).

Lateralised ERP measures (e.g. early and sustained posterior contralateral negativity, N2pc, SPCN) may help clarify biases in initial orienting and holding covert spatial attention on threat over shorter time periods ( $\leq 500$  ms) (e.g., Buodo, Sarlo & Munafo, 2010; Eimer, 2014; Fox, Derakshan, & Shoker, 2008; Holmes et al., 2014; Holmes, Bradley, Nielsen, & Mogg, 2009; Kappenman, Farrens, Luck, & Proudfit, 2014). N2pc reflects lateralised cortical activity associated with orienting to stimuli in left versus right visual fields; and early and late components of N2pc reflect its time-course (early N2pc  $\sim 170$ – $250$  ms, late N2pc  $\sim 250$ – $320$  ms after stimulus onset). Findings of early N2pc indicate enhanced rapid orienting to angry faces in individuals preselected for high trait anxiety (Fox et al., 2008), and to phobia-related pictures in specific fear disorder (Buodo et al., 2010). Late N2pc did not show trait anxiety-related bias for angry faces (Fox et al., 2008); and bias for phobic stimuli was reversed in late N2pc, suggesting initial orienting to high fear cues was rapidly followed by avoidance (Buodo et al., 2010). Other studies indicate rapid initial orienting (early N2pc) to angry faces and general threat pictures in unselected student samples (Holmes et al., 2009; Kappenman et al. 2014). Variation in N2pc findings across studies may partly relate to methodological variables (e.g., participant selection, threat cues) which may influence the subjective salience of threat stimuli. N2pc findings suggest that AB to fear-relevant threat may rapidly fluctuate from initial vigilance to avoidance in under 500 ms (Buodo et al., 2010). If so, absence of AB at 500 ms on the visual-probe task would not necessarily indicate absence of rapid initial orienting to threat (Mogg & Bradley, 2006; see also Section 4.4.6 on temporal instability of ABs). This is relevant to ABM studies which commonly rely on the RT-based AB index at 500 ms to assess change in AB resulting from ABM training. Concurrent lateralised ERP and eye-tracking measures during the visual-probe task may clarify the time-course of ABs for threat.

#### 4.4.3. Influence of symptom profile on ABs in orienting

Anxious individuals vary in comorbidity of anxiety, depression, fear and trauma-related symptoms, which may influence ABs to threat. One common type of comorbidity is between anxiety and depression. Some previous models of anxiety propose that early AB to threat is more likely to be associated with anxiety than depression (e.g., Mogg & Bradley, 1998; Williams et al., 1997, 1988). Evidence from eye-tracking and visual-probe studies suggests that while anxiety relates to increased initial orienting to threat, depression relates more to maintaining spatial attention on negative information (Armstrong & Olatunji, 2012; Caseras, Garner,

Bradley, & Mogg, 2007; Gotlib & Jormann, 2010; Mogg & Bradley, 2005; Mogg, Millar, & Bradley, 2000). Thus, the extent to which an anxious individual maintains attention on negative information may depend on severity of comorbid depression symptoms.<sup>1</sup> A bias to hold spatial attention on negative information may be linked with other cognitive control functions such as ruminative dwelling on and rehearsal of information in working memory, and engagement of elaborative appraisal processes.

ABs in spatial orienting may also vary with comorbidity between generalised anxiety and fear-related anxiety disorders (Mogg & Bradley, 2004). Recent visual-probe-task studies of anxious children suggest that AB towards threat is associated with high internalising (anxiety and depression) symptoms in disorder-free children and in those with distress-related disorders such as generalised anxiety disorder; whereas AB away from threat (avoidance) is found in children who have both high internalising symptoms and fear-related disorders (Salum et al., 2013; see also Waters, Bradley & Mogg, 2014). This pattern of bias in children was found on the visual-probe task across two stimulus durations, 500 and 1250 ms (Salum et al., 2013), with similar findings in another study at 500 ms (Waters et al., 2014). As noted earlier, anxious and fearful adults commonly show an initial AB towards threat at short stimulus durations such as 500 ms (Bar-Haim et al., 2007), which may suggest that fearful children are more likely to show more rapid attentional avoidance after the onset of threat cues than fearful adults.

Threat avoidance is sometimes also found in trauma-related disorders, e.g., attentional avoidance of angry faces at 500 ms in maltreated children with PTSD and a history of severe physical abuse, who may be highly fearful of such stimuli; but not in maltreated children without PTSD or previous abuse (Pine et al., 2005). However, PTSD is not always associated with threat avoidance; e.g., children who had PTSD related to witnessing domestic violence (towards their mothers) showed increased AB towards angry faces at 500 ms, suggesting increased threat monitoring (Swartz, Graham-Bermann, Mogg, Bradley, & Monk, 2011). While evidence of ABs in orienting to threat is mixed in PTSD, AB in threat-distractor interference is more commonly found in PTSD on modified Stroop tasks (for reviews of ABs in PTSD, see McNally, 2006; Hayes, VanElzakker, & Shin, 2012; and for a review of ABs in anxious children, see Dudeney et al. 2015).

One influential view based on neuroscience research is that greater cognitive and behavioural avoidance in anxiety is associated with increased anticipation of experiencing an aversive internal body state, which is mediated by the insular cortex integrating information about current and expected internal body state (Paulus & Stein, 2006). Thus, motivation to avoid subjective distress may contribute to attentional avoidance of threat in anxious individuals. In addition, another type of avoidance motivation, namely, motivation to avoid social disapproval (indexed by high social desirability scores) may be linked with reduced AB towards threat (Broomfield & Turpin, 2005; Eysenck, 1997; Fox, 1993; Ioannou, Mogg, & Bradley, 2004; Mogg, Bradley et al., 2000).

Symptom profile is also relevant to ABM research. For example, anxious individuals with trauma-related symptoms may benefit from attention training which does not encourage threat avoidance (Badura-Brack et al., 2015; see Section 4.4.6). Thus, ABM research

may usefully examine relationships between comorbidity (anxiety, fear, depression, trauma symptoms), pre-existing AB to threat, and changes in symptoms and AB during ABM training.

#### 4.4.4. Influence of stressors on ABs

While stressors characteristically increase state anxiety and emotional distress, they have mixed effects on ABs to threat. Previous models of anxiety suggest that stressors may increase AB in high but not low trait anxious individuals (Williams et al., 1988), increase AB in both high and low trait anxious individuals (Mogg & Bradley, 1998), and sometimes reduce AB to threat via task-related effort or distress-reduction strategies (Cisler & Koster, 2010; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams et al., 1997).

Early studies examined effects of laboratory-induced stressors on the interference effect of stressor-relevant threat words on the modified Stroop task. Findings included increased AB for threat in both high and low trait anxious students (Mogg, Mathews, Bird, & Macgregor-Morris, 1990), suppressed AB for threat in nonclinical and clinical spider phobia (Amir et al., 1996; Mathews & Sebastian, 1993), and suppressed AB in PTSD (Constans, McCloskey, Vasterling, Brailey, & Mathews, 2004). Sometimes AB suppression was accompanied by RT speeding, consistent with task-related effort (Amir et al., 1996; Mathews & Sebastian, 1993), but not always (Constans et al., 2004), suggesting another mechanism was also involved.

Laboratory-induced stressors also have mixed effects on ABs in orienting to threat. For example, at 500 ms on the visual-probe task, they increased AB to threat words in both high and low trait anxious adults (Mogg et al., 1990), or had no effect (Mogg, Bradley, & Hallowell, 1994), or induced avoidance of emotional faces in socially anxious individuals (Mansell, Clark, Ehlers, & Chen, 1999). In an eye-tracking study, socially anxious individuals under social-evaluative stress showed faster initial orienting to emotional faces, but spent less time looking at them (Garner et al., 2006), indicative of a vigilance-avoidance pattern of AB.

Others examined effects of real-life stressors on AB. For example, pre-examination-related stress increased AB towards threat words in high but not low trait anxious students (MacLeod & Mathews, 1988; Mogg et al., 1994). More intense real-life stressors, such as battlefield-like stress in soldiers and war-related stress in civilians, were associated with greater avoidance of threat words (Bar-Haim et al., 2010; Wald et al., 2011). Threat avoidance was also related to increased emotion distress and psychopathology, suggesting that it may not convey emotional benefit and may be maladaptive (Bar-Haim et al., 2010; Wald et al., 2011).

In summary, anxious individuals under stress sometimes show increased AB to threat, and sometimes show AB suppression or threat avoidance, which may partly depend on the severity of the stressor. Variation in effects of stressors on ABs may reflect opposing influences on attention from bottom-up threat-salience evaluation processes (biasing attention towards threat) and top-down processes, which may maintain attention on threat, or they may bias attention away from threat (e.g., by task-related effort or distress-reduction strategies). It would be helpful to clarify further the mechanisms underlying AB suppression and threat avoidance associated with stressors, and how these may differ from AB suppression and threat avoidance induced by ABM-threat-avoidance training.

#### 4.4.5. Influence of trait attention control on ABs

Several studies evaluated the proposal that anxious individuals with high trait attention control are better able to effortfully regulate attention responses to threat than anxious individuals with poor attention control (Derryberry & Rothbart, 1997; Lonigan

<sup>1</sup> Regarding the specificity of ABs to anxiety versus depression, it may also be noted that a widely-used index of trait anxiety, i.e., Spielberger State-Trait Inventory, contains both anxiety-related and depression-related items, e.g., 'I feel inadequate'; 'I feel like a failure' (Bieling, Antony, & Swinson, 1998). Thus, ABs associated with this trait measure may relate more to mixed anxiety/depression symptoms (i.e., negative affectivity) than anxiety symptoms per se.

et al., 2004, Section 2.7). Supportive evidence includes Derryberry and Reed's (2002) findings of relationships between attention control, trait anxiety and AB in orienting to threat, which depended on the exposure duration of the stimuli on a spatial-attention task. Anxious adults showed enhanced AB to threat cues at 250 ms (consistent with initial orienting to threat) which was unaffected by trait attention control. However, at 500 ms (presumed to allow greater influence of top-down control processes), only those with both high trait anxiety and poor trait attention control continued to show AB to threat. Other studies using the visual-probe task showed that youth who have both high trait negative affect and poor effortful control have increased AB for threat words at 1250 ms (Lonigan & Vasey, 2009), and children with both high fearful temperament and poor attention control have increased AB for angry faces at 500 ms (Susa, Benga, Pitică, & Miclea, 2014). In a modified Stroop study, AB to emotional faces, including angry faces, was greater in students who had both high trait anxiety and poor attention control (Reinholdt-Dunne et al. 2009).

However, not all results are as expected. For example, while increased AB to general threat pictures was associated with poor attention control in students with high post-traumatic stress, this occurred at 150 rather than 500 ms on a visual-probe task (Bardeen & Orcutt, 2011). Also, effortful control did not influence AB in anxiety-disordered youth (Vervoort et al., 2011). Comparison of results is complicated by methodological differences (e.g. in samples, tasks, threat stimuli, stimulus durations). Nevertheless, despite some inconsistencies, several findings support the proposal that high trait attention control attenuates AB for threat in anxious individuals. Thus, interventions which improve attention control may help anxious individuals regulate both their emotional and attention responses to threat.

#### 4.4.6. Temporal instability of ABs in attention orienting

Mixed findings of anxiety-related AB may also arise from temporal instability. As noted earlier (Section 2.6), if an anxious individual rapidly switches between vigilant and avoidant responses to threat, this may result in an unstable pattern of AB (Mogg & Bradley, 1998), which may manifest as little or no bias when averaged across a large number of trials. Several studies have examined within-task variability of AB scores on the visual-probe task (Badura-Brack et al., 2015; Bernstein & Zvielli, 2014; Zvielli, Amir, Goldstein & Bernstein, 2015; Zvielli, Bernstein & Koster, 2014). One method assesses trial-by-trial AB variability by comparing RTs from pairs of threat-congruent and threat-incongruent trials, which occur close together in time during the task (Zvielli et al., 2014). This RT difference is comparable with the standard overall AB index (Section 1.1), so this method generates multiple AB scores, from which measures of AB variability are derived. Zvielli et al. (2014) examined relationships between specific fear disorder, AB variability, and standard AB measures at 200 and 500 ms. Regression analyses indicated that fear disorder was independently associated with greater AB variability at 200 ms and 500 ms (which suggested rapid fluctuations between vigilance and avoidance), and also with increased AB to threat on the standard AB index at 200 ms, but not 500 ms. These findings were not explained by RT variability.

Badura-Brack et al. (2015) assessed AB variability from multiple blocks of trials (rather than trial-by-trial variability). In two ABM studies of patients with PTSD, control attention training (visual-probe-training task with probes equally likely to replace threat and nonthreat cues) reduced PTSD symptoms and AB variability, but did not affect the standard AB index at 500 ms (which showed no overall bias to threat across both studies in PTSD patients). ABM-threat-avoidance training did not reduce PTSD symptoms or AB measures. Badura-Brack et al. suggested that reduction in AB

variability reflected improvement in cognitive control (due to repeated practice on the control attention training task), which in turn reduced PTSD symptoms.

Further research may usefully clarify relationships between anxiety, standard AB, RT variability, and AB variability (e.g., using the visual-probe task with concurrent eye-tracking). RT variability is linked with psychopathology and poor attention control (e.g., Bastiaansen, van Roon, Buitelaar, & Oldehinkel, 2015; Weissman, Roberts, Visscher, & Woldorff, 2006), and both AB variability and RT variability may contribute to low reliability of RT-based measures of standard AB. Research into AB variability not only has implications for AB assessment, but has also led to a novel ABM training method aimed at reducing AB variability and improving top-down cognitive control (Zvielli et al., 2015; see Section 5.3).

#### 4.4.7. Influences of other experimental variables on AB measurement

Other methodological factors which reduce error variance in RT measurement are important in assessing ABs, such as controlled testing environments, millisecond accuracy in stimulus and response timing, sufficient RT data for estimating measures of central tendency in each condition when calculating summary AB scores, and dealing with RT outliers in analyses (Ratcliff, 1993). For example, response devices that have millisecond accuracy avoid variability in measurement of RTs found with some computer keyboards, which may obscure ABs (Mogg & Bradley, 1995). Also, testing participants individually in darkened laboratories may not only minimise auditory and visual distraction, but also enhance the subjective salience of threat cues. Evidence indicates that threat cues are evaluated as more aversive if viewed in a dark rather than well-lit room (Grillon et al., 1999; Nakashima, Morimoto, Takano, Yoshikawa, & Hugenberg, 2014). As ABs are influenced by the subjective salience of threat cues, as determined by threat-salience evaluation processes (Mogg & Bradley, 1998), methodological factors which affect subjective threat salience may influence ABs. For example, ABs may be less reliably apparent for mild threat cues (e.g., threat words) in anxious individuals tested in well-lit settings. This has implications for ABM research where experimental control over ambient testing conditions may be difficult to achieve (e.g., clinic, home settings).

#### 4.5. Motivational and goal-related functions of ABs in orienting

Consideration of the motivational and goal-related functions of ABs may explain why they are influenced by diverse variables, discussed earlier. The framework assumes that ABs are driven by both top-down and bottom-up processes, which prioritise goal-relevant stimuli and task-irrelevant threat stimuli, respectively. Empirical evidence indicates that an individual's motivational and goal priorities exert both automatic and strategic influences not only on attention orienting (e.g., Vogt, de Houwer, Crombez & Van Damme, 2013) but also on other cognitive processes (e.g., cognitive flexibility; see Custers & Aarts, 2010; for a review).

A primary role of ABs in attention orienting towards or away from threat may be to support the current motivational or goal priorities of the individual, such as to detect and identify potential threats (automatic orienting to threat, and interrupt goal-directed attention and motor responses); to promote elaborative evaluative processing of negative stimuli (maintain attention); to minimise subjective discomfort (threat avoidance); and to support task-focused processing (suppress AB in orienting to task-irrelevant threat). Selection of priorities may depend on individual differences (e.g., relative dominance of bottom-up threat-salience evaluation and top-down cognitive control systems; distress tolerance; developmental factors; comorbidities between

generalised anxiety, fear and depression) and task-related and situational factors (e.g., threat severity and exposure duration; task demands; external stressors). Thus, ABs in orienting to threat cues may reflect the motivational/goal priorities currently dominant in a particular situation across both bottom-up and top-down cognitive systems.

According to the framework, ABs in orienting towards or away from threat depend on the extent to which orienting processes are biased by bottom-up mechanisms, which support threat evaluation/detection (biasing both bottom-up and top-down orienting towards threat), and top-down mechanisms which support goals that may maintain AB on task-irrelevant threat (e.g., threat monitoring goal) or oppose it (e.g., task-focused goal; distress-reduction goal). Thus, it predicts that variables which modify these goals and the influence of the bottom-up threat-salience evaluation mechanism on processing will modify ABs. For example, enhancing goal-directed task-focused cognitive control should reduce the influence of the bottom-up salience-evaluation system on other processes, and attenuate anxiety-related ABs in orienting to task-irrelevant threat. Hence, improving cognitive control should reduce AB in orienting towards threat in anxious individuals who show this bias, and reduce AB variability in those with unstable AB. The effect of improving cognitive control on AB in anxious individuals who show threat avoidance is more difficult to predict and may depend on the extent to which pre-existing threat avoidance relates to task-related effort or distress-reduction strategies. Thus, while improving cognitive control may reduce anxiety and improve emotion regulation, its effects on ABs in orienting to threat may be more variable.

This framework may explain not only variability of AB findings (e.g., across different anxious samples, tasks and test occasions), but also evidence of AB towards threat in anxiety averaged across many studies (Bar-Haim et al., 2007) which may reflect pervasive bias from the bottom-up threat-salience evaluation mechanism on bottom-up and top-down attention processes in anxious individuals.

#### 4.6. Do ABs in orienting to threat predict treatment outcome in anxiety?

Given that not all anxious individuals show an AB in orienting towards threat, researchers have investigated whether this might influence response to treatment. Several visual-probe studies suggest that biased spatial orienting towards threat may predict treatment outcome, as individuals with anxiety disorders who showed an AB towards mild threat cues (e.g., pictures of angry faces shown for 500 ms) prior to treatment, subsequently responded better to treatments such as CBT and ABM, than those who showed no bias or avoidance (Amir, Taylor, & Donohue, 2011; Price, Tone, & Anderson, 2011; Waters, Mogg, & Bradley, 2012; Waters et al., 2015). However, some results are mixed as, in one sample of anxious children, pretreatment AB towards severe threat cues (e.g., images of aimed gun, biting dog) predicted poorer initial response to 10-session CBT, but better response to a further 10 sessions of more intense CBT (Legerstee et al., 2009, 2010), indicating the need to take account of the severity of the threat cues in AB assessment, and the duration and intensity of the treatment.

The mechanisms underlying a predictive relationship between pretreatment AB and treatment response are uncertain. If, as suggested earlier, threat avoidance is associated with greater anticipation of experiencing an aversive internal body state (Paulus & Stein, 2006), a correlation between pretreatment threat avoidance and poorer treatment outcome may relate to individual differences in distress tolerance. As prediction of aversive internal body states has been linked with insula function in anxiety (Paulus

& Stein, 2006), it would seem useful to examine relationships between neuroimaging and AB predictors of treatment outcome in anxiety disorders (Shin et al., 2013). The relationship between pretreatment AB and treatment response warrants further investigation given its potential clinical relevance; for example, anxious individuals who show strong threat avoidance may require more extensive treatment.

## 5. Implications for ABM

As noted earlier, a major problem for ABM research is that the overall efficacy of ABM-threat-avoidance training seems weak, with some studies reporting that it reduces both AB and anxiety, while others report no effect on either outcome, particularly when used in home settings (Cristea, Kok et al., 2015; MacLeod & Clarke, 2015), which limits its utility. However, other ABM methods may be more promising (e.g., ABM-positive-search training; Waters et al., 2015, 2016). Thus, current challenges for ABM research include identifying ABM methods which are effective in reducing anxiety vulnerability and treating anxiety disorders, and clarifying the cognitive mechanisms which underlie their effects.

To recap, this framework proposes that anxiety stems from imbalance between bottom-up and top-down systems involved in threat evaluation, attention and cognitive control (Fig. 4). Core components include a *bottom-up mechanism evaluating the motivational salience of stimuli* (which automatically assesses the motivational importance of threat cues, integrates top-down and bottom-up sources of information, and modulates and biases other processes); and top-down *goal-directed inhibitory control*, which supports positive and task-focused goal engagement, and opposes influence from the bottom-up threat-salience evaluation system (i.e., it maintains an adaptive goal-oriented processing mode, and co-ordinated functioning of cognitive control processes, in the presence of minor threat cues). If this view is correct, what kinds of ABM interventions may be effective in correcting this imbalance?

### 5.1. ABM-threat-avoidance training

ABM-threat-avoidance training may not be ideal in correcting imbalance between bottom-up and top-down cognitive systems involved in threat processing, as involvement of inhibitory control processes which support adaptive goal-focused activity seems relatively limited. ABM-threat-avoidance training using the modified visual-probe task requires participants to repeatedly direct attention away from a spatial location where a threat cue has just appeared and direct it towards the location of a neutral target-probe stimulus (e.g., dot or arrow). It is designed to counter an automatic bias in spatial orienting towards threat via habit change, so involvement of effortful top-down control processes may be relatively low; for example, participants are typically not informed about its goal of directing attention away from threat. Also, the target-probe appears when the threat stimulus is no longer present (Fig. 1, upper panel), so there is no direct processing conflict between task-relevant information (probe) and task-irrelevant threat. Instead, competition in processing is between threat and neutral cues which are both task-irrelevant. Hence, goal-directed inhibitory control processes may be less strongly engaged by the visual-probe task used in ABM-threat-avoidance training, compared with other tasks where the task-relevant nontarget and task-irrelevant threat information appear simultaneously, such as the modified Stroop task, or the visual-search task in which nontargets are embedded among threat distractors.

Another limitation of ABM-threat-avoidance training, noted earlier, is that not all anxious individuals show an attention bias in

spatial orienting towards threat, which not only questions the appropriateness of ABM-threat-avoidance training for them (e.g., Dudeney et al., 2015; Salum et al., 2013; Van Bockstaele et al., 2014; Waters et al., 2014), but also questions the assumption that this AB towards threat plays a primary causal role in anxiety. Moreover, threat avoidance is not a reliable feature of healthy nonanxious individuals (Bar-Haim et al., 2007), which is an assumption underlying ABM-threat-avoidance training. Another concern is that while threat avoidance may have a short-term effect in reducing immediate emotional distress, it may not be an effective long-term coping strategy (Bar-Haim et al., 2010; Cisler & Koster, 2010; Hallion & Ruscio, 2011; Mogg & Bradley, 1998; Van Bockstaele et al., 2014; Wald et al., 2011).

## 5.2. ABM-positive-search training

Interventions which actively recruit top-down processes (in particular, goal-directed inhibitory control) to oppose processing of task-irrelevant threat may be more promising than ABM-threat-avoidance training in reducing anxiety. An example of such an approach is ABM-positive-search training, which encourages a positively-focused attention search mode, combined with inhibition of threat distractors that appear simultaneously with goal-relevant target stimuli (Dandeneau et al., 2007; De Voogd et al., 2014; Waters et al., 2013, 2015, 2016). Findings from these studies indicate that ABM-positive-search training reduces self-reported stress and cortisol measures of stress reactivity in adults (Dandeneau et al., 2007), social anxiety symptoms in youth (De Voogd et al., 2014) and clinician-rated symptom severity of anxiety disorders in children (Waters et al., 2013, 2015, 2016). Anxiolytic effects of ABM-positive-search training have been found in clinic/laboratory (De Voogd et al., 2014; Waters et al., 2013), work (Dandeneau et al., 2007) and home settings (Waters et al., 2015, 2016).

Regarding effects of ABM-positive-search training on AB, most studies found changes in AB measures for threat and positive stimuli, although these changes varied across studies. ABM-positive-search training reduced ABs to threat on modified Stroop and visual-probe tasks in individuals with low self-esteem (Dandeneau et al., 2007), facilitated detection of positive relative to negative faces on the visual-search task in anxious youth (De Voogd et al., 2014), and increased AB for positive relative to neutral faces on the visual-probe task in children with anxiety disorders (Waters et al., 2013). In two studies assessing AB at 500 ms on the visual-probe task, clinically anxious children did not show AB towards threat (angry relative to neutral faces) before or after training, or change in AB to threat during ABM-positive-search training; although they did show anxiety reduction (Waters et al., 2013, 2015).

In collaboration with Allison Waters, Melanie Zimmer-Gembeck, Michelle Craske and Danny Pine, we have been involved in developing an enhanced version of ABM-positive-search training for anxious children (Waters et al., 2015, 2016). This uses pictures of everyday scenes as targets and distractors, to encourage generalisation across a wide range of stimuli (over 350 pictures are used as targets and distractors). Children are asked to search for examples from two positive target categories, i.e., 'good' images (e.g., happy faces, children playing) or 'calm' images (e.g., book, armchair), which are embedded in picture-arrays of threat or negative distractors (e.g., house on fire, person in hospital). Calm target images are included not only to encourage individuals to search for a wide and varied range of nonthreat cues, but also because, in everyday life, not every situation contains a highly positive stimulus to focus on. ABM-positive-search training includes explicit instructions (e.g., 'look for good', 'look for calm',

'never give up' looking for good and calm) to support maintenance of these goals. Participants are also encouraged to repeatedly verbalise these self-instructions, in accord with the view that verbal mediation supports learning constructive modes of processing (Beck & Clark, 1997).

Enhanced ABM-positive-search training incorporates general recommendations for attention skills training, such as varying the level of task demand and encouraging cognitive flexibility (Diamond, 2013). In each session, initial training requires searching for one target category (e.g., look for good), while later training requires searching for targets from more than one category simultaneously (i.e., look for both good and calm images) to promote flexibility and generalisation. The number of negative distractors on each trial also varies from eight distractors (in  $3 \times 3$  picture arrays) to 15 (in  $4 \times 4$  arrays). Preliminary evaluation of this enhanced ABM-positive-search training for anxiety disorders has been encouraging; e.g., two studies showed significant improvements in a range of symptom measures, and clinician-based diagnostic assessment indicated that about a third to a half of children were free of their principal anxiety disorder after training; and treatment gains on symptom measures were largely maintained at six-month follow-up (Waters et al., 2015, 2016).

ABM-positive-search training could be made even more challenging for adults as training progresses, for example, by mixing blocks of trials with word and pictorial stimuli to promote greater stimulus generalisation and flexibility. To encourage sustained positive goal-directed attention under conditions of high cognitive demand (which may increase susceptibility to distraction, Lavie, 2005), later stages of training could be combined with concurrent tasks (e.g., remembering task-irrelevant number sequences to increase working memory load) or additional auditory distractors (e.g., task-irrelevant words or music). Progressively increasing and varying cognitive demands during training may also counter a common complaint that computer-delivered ABM methods are tedious and boring, which can pose a problem for treatment take-up and compliance, particularly when administered in home settings with little support or supervision (Lau, 2015; Rapee et al., 2013).

To further encourage adaptive balanced functioning of top-down and bottom up systems, ABM-positive-search training could be combined with other tasks into a broader *cognitive bias modification* (CBM) training package with a unifying goal of encouraging positively focused goal-directed processing and inhibitory control over threat processing. For example, CBM-positive training could intermix blocks of trials with different training conditions; e.g., engaging reason-based evaluation by instructing participants to work out positive rather than negative solutions to puzzles or crosswords (designed to have both); or including methods used for modifying interpretative biases, such as generating positive rather than negative words when completing fragments of words or sentences (which involves inhibiting negative solutions). Using a variety of tasks may make training more interesting and so improve compliance. If CBM-positive training is effective in reducing anxiety, then subsequent research could clarify whether it has essential specific components, or whether it is their combination that relates to treatment outcome. This may be more cost-effective and clinically useful, and less time-consuming, than evaluating a series of interventions in turn which target specific cognitive biases, which in isolation may have weak or no effects. Given that this approach has been useful in the development of CBT (another multi-component treatment for anxiety), it may also assist in developing computer-delivered interventions for anxiety.

### 5.3. Other novel ABM training methods

Several other novel ABM methods have recently been described. An animated game version of ABM training was developed for use on mobile phones by Dennis and O'Toole (2014), in which two animated cartoon characters ('sprites') with either angry or smiling expressions appear to burrow into a grass field, and one leaves a trace in the grass. The training task encourages participants to track the path in the grass of the smiling sprite rather than the angry sprite, and feedback on performance is given on each trial. Preliminary findings suggest that single-session training modifies stress reactivity and neural responses to threat (indexed by ERP), but not AB in orienting to threat (indexed by RT), in nonclinical samples (Dennis & O'Toole, 2014; Dennis-Tiway, Egan, Babkirk & Denefrio, 2016).

Another novel ABM task is the person-identity-matching (PIM) task developed by Notebaert, Clarke, Grafton, and MacLeod (2015). This presents pictures of angry or happy faces and requires participants to make matching judgements between pairs of faces, based either on the identity (same vs. different person) of the happy faces or the angry faces. The attend-happy training condition involves neutral discrimination judgements for happy faces and ignoring angry faces. Notebaert et al.'s preliminary results suggest that single-session PIM training is more effective than conventional ABM-threat-avoidance training in modifying self-reported stress reactivity and AB to threat in a nonclinical sample.

Attention Feedback Awareness and Control Training (A-FACT) was developed to increase self-regulatory control of attention responses to threat (Bernstein & Zvielli, 2014; Zvielli et al., 2015). A-FACT is based on proposals that attentional responses to threat in anxiety may be unstable and rapidly fluctuate between vigilance and avoidance (see Section 4.4.6 on temporal instability of ABs), and that promoting awareness and top-down cognitive control of ABs may reduce anxiety. In Zvielli et al.'s (2015) version of A-FACT, participants first completed an initial assessment visual-probe task and were then told that their attention was affected by threat stimuli, and that they should try to use feedback, provided during a subsequent ABM visual-probe task, to reduce their AB. Trial-by-trial feedback on ABs reflected the extent to which RTs to probes replacing threat-neutral picture pairs differed from baseline RTs on trials with neutral-neutral picture pairs (see Zvielli et al., 2015; for details). Their preliminary results suggest that single-session A-FACT reduces ABs (towards and away from threat), AB variability, and stress reactivity in high trait anxious individuals.

To our knowledge, none of these novel methods has yet been evaluated with individuals with anxiety disorders (unlike ABM-threat-avoidance and ABM-positive-search training). Cristea, Kok, et al. (2015) caution against a proliferation of new variations of ABM, as there is a need for large scale RCTs with clinical samples using an approach shown to be promising in treating anxiety disorders. Enhanced ABM-positive-search training appears to be a promising candidate for such research.

### 5.4. Do different mechanisms underlie effects of ABM-threat-avoidance and ABM-positive-search training?

A potential concern with a multi-function approach to ABM or CBM methods, which engage a range of top-down functions to oppose bottom-up prioritisation of threat processing, is that such methods are not process-pure which makes it difficult to clarify which specific mechanisms may be responsible for its effectiveness. However, anxiety may not be caused by dysfunction in an isolated process, which may explain why methods which target more than one process may be more effective. To examine the effect of ABM on

cognitive processes in anxiety, a variety of threat-related and baseline cognitive functions (involved in bottom-up and top-down stimulus-evaluation, attention and cognitive control) could be assessed before and after treatment. Consequently, treatment-related changes in each of these functions can be related to clinical outcome variables. This may clarify the extent to which change in anxiety symptoms relates to change in particular functions. Such assessments may include RT-based measures of ABs in spatial orienting (e.g., visual-probe task), and inhibition of distractors (e.g., modified flanker and Stroop tasks). Eye-tracking can also be used to assess ABs in spatial orienting (e.g., latency and direction of initial gaze shift, gaze dwell time; Armstrong & Olatunji, 2012). Moreover, neural ERP-based measures can be used to investigate initial spatial orienting of attention and maintaining attention on threat cues (Buodo et al., 2010; Fox et al., 2008; Holmes et al., 2014; see Eimer, 2014 for a review of these methods), and fMRI and MEG to examine activity of brain networks involved in stimulus evaluation, attention, and cognitive control (e.g., Buhle et al., 2014; Etkin & Wager, 2007; Maratos et al., 2009; Monk et al., 2008; Pessoa & Adolphs, 2010).

Such research may reveal that ABM methods influence multiple processes. For example, while ABM-threat-avoidance training may primarily promote threat-avoidant orienting (as it is designed to do), it may also engage goal-directed inhibitory control (Chen, Clarke, Watson, MacLeod, & Guastella, 2015). Correspondingly, while ABM-positive-search training may primarily promote goal-directed inhibitory control, it may also engage threat-avoidant orienting, given that the task involves orienting towards goal-relevant positive cues and away from task-irrelevant threat. However, ABM-positive-search training, in particular, the enhanced version of Waters et al. (2015, 2016), differs from ABM-threat-avoidance training by *explicitly encouraging adaptive attention-search goals* (e.g., look for good and calm, which have generalised utility beyond the training task), and *greater coordinated use of multiple cognitive control functions which prioritise goal-directed processing and oppose threat-distractor processing*. Within the proposed framework (Fig. 4), these cognitive control functions include: (i) *goal-directed inhibitory control*, which supports threat-distractor inhibition, and is actively engaged by presenting good/calm targets and threat distractors simultaneously, and explicitly prioritising the former as goal-relevant, (ii) *controlled (top-down) orienting towards goal-relevant positive and nonthreat information, and away from goal-irrelevant threat cues*, which is directed by explicit instructions to look for good and calm targets, (iii) *maintaining representations of adaptive attention-search goals in working memory*, which is supported by repeated self-verbalisations of those goals (e.g., "look for good", "look for calm"), (iv) *attention flexibility*, which is encouraged by switching between good and calm target categories, and also pursuing both goals simultaneously, during training sessions and (v) *reason-based appraisal*, which is engaged by repeated task-related appraisals of threat cues as goal-irrelevant (hence, low importance) during attention search. Together, these top-down cognitive control functions may downregulate bottom-up processes involved in threat-salience evaluation. Thus, an important difference between the ABM-positive-search training and ABM-threat-avoidance training methods may be the relative extent to which they engage goal-directed cognitive control processes to oppose threat processing.

Thus, predictions can be made from the framework regarding which ABM methods may be more effective than others in reducing anxiety (e.g., ABM-threat-avoidance training versus ABM-positive-search training). It also predicts that training avoidant orienting may not be an essential ingredient of effective ABM. For example, methods which are designed to promote goal-directed inhibitory control over threat distractor processing, without avoidant

orienting, may be effective in reducing anxiety and attenuating ABs in orienting to threat. This might be examined, for example, using a Stroop-type training task (which does not engage spatial orienting), which presents composite stimuli which have both nonthreat and threat attributes (e.g., threat words presented in different colours), and training participants to focus on goal-relevant nonthreat attributes (colour) and ignore goal-irrelevant threat attributes.

However, the choice of goal-relevant stimuli may be another important parameter of ABM tasks. In the enhanced version of ABM-positive-search training (Waters et al., 2015, 2016), the goal-relevant stimuli comprise a wide range of positive and calming images commonly encountered in everyday life. This is intended to encourage generalisation across a wide range of situations and make training more demanding (relative to using a more restricted range of target stimuli, e.g., happy faces, neutral probes, colours). It may also enhance positive mood, which may contribute to ABM efficacy. The use of positive targets may make training more enjoyable and engaging, which may help treatment compliance (Rapee et al., 2013). However, the anxiolytic effect of ABM-positive-search training may not necessarily depend on using highly positive targets, given that it also includes calm targets which have relatively mild positive valence (e.g., book, armchair). Further research could separately manipulate type of ABM training method and type of goal-relevant stimuli to identify effective ingredients.

As the framework predicts that improving goal-directed inhibitory control over threat processing will reduce anxiety, this raises the question of whether ABM-threat-avoidance training may be improved by instructions explicitly promoting the goal of being threat avoidant in both training and daily activities. However, concerns have been raised that this avoidant attentional strategy may not have long-term benefit, discussed earlier. Also, it may be easier and more adaptive to strengthen positive/nonthreat goal priorities (i.e., to attend to positive, calming and task-relevant information) than to strengthen goal priorities which specify what to avoid.

### 5.5. Role of exposure

In refining ABM, it would also be useful to examine the contributory role of exposure. Exposure is a well-established treatment approach for reducing the subjective threat value of feared stimuli. Fear extinction, which results from threat exposure, is thought to depend on increasing the inhibitory effect of frontal brain regions, which support top-down cognitive control, on subcortical (amygdala) regions involved in fear learning and threat-salience evaluation (e.g., Bishop, 2007; Sotres-Bayon, Cain, & LeDoux, 2006). Thus, the mechanisms which may underlie anxiolytic effects of exposure seem similar to those described in the proposed framework. Hence, the combination of engaging adaptive goal-directed cognitive control functions during exposure to multiple diverse threat cues (as in ABM-positive-search training) may be more effective in reducing anxiety than equivalent exposure alone.

In some ABM studies, ABM-threat-avoidance training and control conditions, which involved a similar level of exposure to threat cues, both reduced anxiety, which could be explained by exposure or possibly by placebo effects (e.g., Boettcher et al., 2013; Carleton et al., 2015; Heeren, Mogoş, McNally, et al., 2015; McNally et al., 2013; Rapee et al., 2013). One study unexpectedly found that training attention *towards* threat reduced social anxiety more than a control training condition; which may have been due to the attend-threat training condition enhancing exposure to threat cues (Boettcher et al., 2013). The contribution of exposure to ABM-positive-search training can be examined by comparing it with

control conditions which manipulate exposure to threat cues independently of goal-directed attention search for positive versus threat information (e.g., control conditions which involve exposure to threat cues but without engaging positive attention search and threat-distractor inhibition; or involve positive attention search in the presence of nonthreat rather than threat distractors).

### 5.6. Should ABM-positive-search training be construed as ABM-threat-avoidance training?

Some researchers have referred to ABM-positive-search training as an example of “avoid-threat ABM training” (e.g., MacLeod & Clarke, 2015, p. 66). However, it seems appropriate to distinguish between ABM-positive-search and ABM-threat-avoidance training for several reasons. First, they appear to differ in clinical efficacy in reducing anxiety symptoms. Although not yet directly compared with each other, preliminary findings suggest that superior efficacy of ABM-positive-search may be particularly apparent when ABM training is delivered in home settings (Waters et al., 2015, 2016). Second, the methods have differing underlying assumptions. ABM-threat-avoidance training assumes that the anxiolytic effect of ABM training depends on reducing AB to threat, as indexed by AB in orienting towards threat; whereas ABM-positive-search training does not rely on this assumption. Third, these ABM methods may differ in effects on goal-directed top-down cognitive control functions (see Section 5.4). Fourth, the term, ABM-threat-avoidance-training does not accurately reflect the operationalisation of ABM-positive-search-training, which instructs participants to prioritise attention-search goals for positive (e.g., good/calm) information, rather than threat avoidance. Fifth, these methods may differ in suitability for anxious individuals; as ABM-threat-avoidance training may be inappropriate for anxious individuals who do not show pre-existing AB in orienting towards threat (Eldar et al., 2012; Van Bockstaele et al., 2014), whereas ABM-positive-search training seems potentially suitable for all anxious individuals, irrespective of whether they show AB in orienting towards or away from threat, or unstable AB. Sixth, there seems to be no advantage in construing ABM-positive-search training as ABM-threat-avoidance training, and it may have disadvantages (e.g., it may imply the methods have similar efficacy or underlying assumptions).

### 5.7. Does the anxiolytic effect of ABM training depend on its effectiveness in reducing AB to threat?

ABM-threat-avoidance training is based on the premise that anxious individuals have an enhanced AB towards threat, and interventions which reduce this AB should reduce anxiety. For example, MacLeod and Clarke (2015, p. 59) propose that AB for threat is “a hallmark cognitive characteristic” of anxious individuals and that the effectiveness of ABM training in reducing anxiety depends on its effectiveness in reducing attention to threat. Hence, failures of ABM training to reduce anxiety may be explained by its failure to reduce AB to threat.

This proposal raises several considerations. First, many ABM studies find no evidence of AB in orienting to threat in anxious individuals before ABM training (e.g., Boettcher et al., 2013; Britton et al., 2013; Carleton et al., 2015; Eldar et al., 2012; Heeren, Mogoş, McNally, et al., 2015; McNally et al., 2013; Waters et al., 2015). This concurs with recent reviews indicating that AB in orienting towards threat is not consistently found in anxiety (Dudney et al., 2015; Van Bockstaele et al., 2014; see also Heeren, Mogoş, Philippot, & McNally, 2015). As noted earlier (Section 4.4), absence of AB in orienting to threat in anxious individuals may relate to several variables, such as high fear, trauma or stress, effortful

attention control, or unstable AB. This questions the premise of ABM-threat-avoidance training that anxious individuals are strongly characterised by AB in orienting to threat (indexed by the visual-probe task), and its reduction is necessary for anxiety reduction.

Second, some findings indicate that attention-training methods, including ABM-threat-avoidance and ABM-positive-search training, can reduce anxiety without reducing AB in orienting to threat. For example, two studies of ABM-positive-search training found reduction in anxiety symptoms, without change in this AB index on the visual-probe task (Waters et al., 2013, 2015). Other studies compared three different visual-probe-training tasks: ABM-threat-avoidance, designed to reduce AB to threat (probes more likely to replace nonthreat than threat cues); inverse-ABM, designed to increase AB to threat (probes more likely to replace threat than nonthreat cues); and control attention training which was not expected to modify AB (probes equally likely to replace threat and nonthreat cues) (Boettcher et al., 2013; Heeren, Mogoş, McNally et al., 2015; McNally et al., 2013). These showed reduction in anxiety symptoms from pre- to post-training, irrespective of the type of training task, and without reducing AB to threat on spatial-attention tasks. Two of these studies also assessed attention control (indexed by the interference effect of neutral distractors on the Attention Network Task; Fan, McCandliss, Sommer, Raz, & Posner, 2002), which indicated that anxiety reduction was accompanied by improved attention control (Heeren, Mogoş, McNally et al., 2015; McNally et al., 2013). Thus, attention training methods (including ABM-threat-avoidance training) may have an anxiolytic effect, mediated by improved cognitive control, which does not depend on reducing AB in orienting to threat. Also, training direction of AB away from threat may convey little or no additional benefit (see also Badura-Brack et al. 2015). This requires further evaluation, e.g., including control conditions which do not involve extended attention training.

Third, interpretation of findings of AB change is complicated by a methodological limitation of many ABM studies, which is the use of the same or similar paradigm to modify and assess AB (e.g., as noted by Amir et al., 2009; Cristea, Kok, et al., 2015). Thus, it is unclear whether AB change, if found, has generalised beyond the specific task demands. Participants may show greater threat avoidance on probe-based assessment tasks after ABM-threat-avoidance training (relative to pre-training), because they learned the rule during training that *probes rarely appear in the position just occupied by a threat cue*. Hence, change in the AB index from pre- to post-training may reflect (implicit or explicit) learning of this rule, rather than general change in AB to threat. This problem is not resolved by the use of different stimuli, or differing probe-based tasks that share the same rule in ABM training and AB assessment (e.g., visual-probe and spatial-cueing tasks; see Fig. 1 upper and middle panels). Thus, additional AB assessment measures which use tasks and stimuli different to those used in training would be helpful (e.g., visual-probe or modified Stroop tasks to assess effects of ABM-positive-search training on AB, as in Dandaneau et al., 2007; Waters et al., 2013, 2015).

Fourth, effects of ABM training on self-reported anxiety may be influenced by response bias. For example, training an individual to repeatedly direct attention to the less negative alternative of two items could subsequently bias responses on self-report measures of anxiety towards less negative response choices, resulting in lower anxiety scores. Thus, use of independent clinician-based assessments and physiological measures of anxiety seems helpful.

Fifth, AB to threat is multi-faceted. AB indices of orienting to threat and threat-distractor interference are often uncorrelated (Cisler et al., 2009); so absence of AB in orienting towards threat

may not necessarily indicate absence of AB in threat-distractor interference. While most ABM studies assess AB in orienting (e.g., visual-probe task), some assess threat-distractor interference (e.g., modified Stroop task), or use AB measures which may reflect both (e.g., spatial-cueing, visual-search tasks; see Section 4.4.1). Thus, the question of whether the anxiolytic effect of ABM depends on AB reduction should be clarified to indicate whether it refers to AB in initial orienting and/or AB in threat-distractor interference.

In summary, several issues prevent a clear answer to the question of whether the anxiolytic effect of ABM training depends on reduction of AB to threat. Assessments of AB and anxiety are susceptible to potential confounds (e.g., use of similar AB training and assessment tasks; response bias in self-report measures; experimenter demand effects), some of which may contribute to findings of stronger ABM effects in laboratory than home settings, which highlights the need for rigorous RTCs to evaluate ABM effects (for further discussion, see Cristea, Kok, et al., 2015; Heeren, Mogoş, Philippot, & McNally, 2015). Also, evidence of relationships between pre-existing AB to threat, AB reduction, and anxiety reduction is mixed; as some findings suggest that ABM and control attention training may reduce anxiety, without reducing AB in orienting to threat, perhaps by improving cognitive control (e.g., Badura-Brack et al. 2015; Heeren, Mogoş, McNally et al., 2015; Boettcher et al., 2013; McNally et al., 2013). Also, the operationalisation of AB to threat would benefit from clarification (e.g., initial orienting to threat, maintained attention, threat-distractor interference). Taken together, these considerations indicate that the question may be usefully revised as follows: Does the anxiolytic effect of ABM training relate to its effectiveness in modifying one or more attention variables, such as reducing AB in orienting towards threat (initial orienting and/or maintained attention), reducing AB in threat-distractor interference, reducing AB variability, and/or improving attention control? To evaluate this question requires differing experimental tasks to assess and modify AB (to avoid the methodological problem noted earlier), and inclusion of self-report and behavioural measures of attention control.

### 5.8. Summary of proposals relevant to ABM research

The proposed framework (summarised in Fig. 4) builds on and integrates proposals from previous cognitive models of anxiety (Fig. 2), and models of attention and cognitive control (Fig. 3). Its components correspond to core cognitive functions identified by models of attention, cognitive control and stimulus-salience evaluation. The framework has implications for ABM research, because identification of mechanisms and variables that influence ABs to threat may not only facilitate evaluation of ABs (which is a key aspect of ABM research), but also the development of more effective ABM training methods. Here, we summarise some proposals, discussed earlier, which have relevance to ABM research:

- (i) AB to threat is not a unitary construct: its manifestations include ABs in orienting towards and away from threat (i.e., initial orienting to threat, maintained attention on threat, threat avoidance) and AB in threat-distractor interference.
- (ii) ABs in orienting towards and away from threat depend on multi-component bottom-up and top-down cognitive systems (in particular, *bottom-up threat-salience evaluation* and *top-down goal-directed inhibitory control functions*), which reciprocally influence each other (Fig. 4). Anxiety and ABs to threat are consequences of imbalance in these systems. AB in orienting towards threat is unlikely to be a primary cause of anxiety.

- (iii) Anxiety-related ABs to threat are influenced by individual-difference, task-related and situational variables, such as symptom comorbidity (anxiety, depression, fear and trauma symptoms), trait attention control, threat stimulus duration and intensity, and stressors.
- (iv) Anxious individuals do not consistently show AB in orienting towards threat (e.g., on the visual-probe task), and may show threat vigilance, threat avoidance, or unstable AB (rapidly fluctuating between vigilance and avoidance). Despite variability in ABs, an overall anxiety-related AB towards threat may emerge when averaged across studies (Bar-Haim et al., 2007), which may reflect the dominant influence of the bottom-up threat-salience-evaluation system over other processes, including automatic and controlled orienting, in anxious individuals.
- (v) Variation in ABs in orienting towards or away from threat reflects differing motivational/goal-related influences on attention from bottom-up and top-down systems. The bottom-up system supports automatic rapid evaluation and detection of motivationally salient stimuli (which biases other bottom-up and top-down processes, including AB in initial orienting to threat). The cognitive control system exerts goal-directed influences on orienting, which may maintain attention on threat (threat monitoring goal), suppress AB in orienting to threat or elicit AB away from threat (e.g., reflecting task-focused or distress-reduction goals).
- (vi) The anxiolytic effect of ABM training (and other interventions, such as exposure-based treatments) depends on modifying the balance between top-down and bottom-up systems. Hence, ABM training may be particularly effective in reducing anxiety if it strongly engages top-down cognitive control functions (in particular, goal-directed inhibitory control, which downregulates the bottom-up threat-salience-evaluation system, and supports threat-distractor inhibition and goal-directed processing) during exposure to multiple, diverse task-irrelevant threat cues. Moreover, as components of the cognitive control system work in a unitary manner to support goal-directed thought and behaviour (Duncan, 2010; Miyake & Friedman, 2012; Miyake et al., 2000), the anxiolytic effect of ABM training may be further enhanced if ABM training requires coordinated engagement of multiple top-down functions during exposure to task-irrelevant threat (i.e., goal-directed inhibitory control; top-down controlled orienting to goal-relevant information; cognitive flexibility in switching between adaptive attention-search goals; maintaining attention-search goals in working memory by self-verbalisations; and task-related appraisals of threat cues as goal-irrelevant).
- (vii) Training anxious individuals to orient attention away from threat (as in ABM-threat-avoidance training) may not be an essential ingredient of effective ABM training. For example, strengthening threat-distractor inhibition, without involving spatial orienting, may be beneficial.
- (viii) The anxiolytic effect of ABM-positive-search training may not depend on using highly positive target stimuli, as it also uses calm nonthreat targets which have relatively mild positive valence. However, inclusion of highly positive targets may enhance its efficacy (e.g., by improving positive mood, engagement with training, and generalisation across diverse stimuli).
- (ix) ABM training which enhances top-down cognitive control, including threat-distractor inhibition, may reduce anxiety symptoms of anxious individuals, irrespective of whether they show pre-existing AB in orienting towards threat, away from threat, or unstable AB.

## 6. Related issues

The focus of this article on cognitive models of anxiety and AB and ABM in anxiety prevents detailed consideration of other issues of potential relevance to the framework described here, such as ABs in other conditions, and interpretation bias modification in anxiety, which are briefly mentioned in this section.

### 6.1. ABs in other conditions

Individual differences in ABs are not specific to threat cues in anxiety, as they are also found for other motivationally or personally salient information, for example, in illness and pain (Hou et al., 2014; Todd et al., 2015); as well as for rewards, such as food cues in obesity (Castellanos et al., 2009) and drug cues in addiction (Field & Cox, 2008; Field, Mogg, & Bradley, 2006). The present framework has potential relevance for such work, given that exaggerated ABs may reflect imbalance between bottom-up automatic processing of stimuli which have high motivational salience for the individual (aversive or reward-related) and top-down cognitive control processes, in a variety of health-related and psychological disorders.

### 6.2. Interpretation bias modification in anxiety

Cognitive models of anxiety, reviewed earlier, not only predict increased attention to threat in anxiety but also a bias in interpretative processes; which is supported by empirical evidence of an increased tendency for anxious individuals to interpret ambiguous information in a negative or threat-related manner (see Mathews & MacLeod, 2005; for a review). Both bottom-up and top-down processes may contribute to this bias, which has been targeted by computer-delivered interpretation bias modification (IBM) training (Lau, 2013; MacLeod & Mathews, 2012). IBM typically presents ambiguous stimuli (e.g., scenarios, pictures, homographs) and requires participants to generate a nonthreatening, rather than threat-related interpretation (e.g., generate a word relevant to the nonthreatening meaning of the ambiguous information). Meta-analytic findings suggest that IBM training has a small effect on reducing negative mood (Cristea, Kok et al., 2015; Hallion & Ruscio, 2011; Menne-Lothmann et al., 2014). As IBM may encourage a response strategy to select less negative answers on self-report measures of anxiety, it would be useful to include physiological outcome measures; for example, by examining associations between self-reported anxiety reduction and changes in amygdala-frontocortical connectivity implicated in threat evaluation (Pessoa & Adolphs, 2010; Buhle et al., 2014), or threat-related startle responses (Grillon, 2008).

## 7. Concluding comments

In summary, the present framework encompasses the hypothesis that anxiety stems from imbalance between bottom-up mechanisms involved in automatic threat evaluation/detection (including automatic stimulus-salience evaluation, orienting, interrupt, alerting and perceptual processing) and a top-down cognitive control system which coordinates multiple functions to support goal-directed thought, action and emotion regulation (including inhibitory control, strategic orienting, attention flexibility, working memory functions, and reason-based appraisal). Bottom-up stimulus-salience-evaluation processes play a key role not only in assessing the motivational importance and threat value of stimuli by integrating multiple sources of information, but also in modulating activity in other bottom-up and top-down processes to prioritise motivationally salient information (Pessoa & Adolphs, 2010). Top-down inhibitory control underpins a wide range of

cognitive control functions (Miyake & Friedman, 2012) and plays a key role in suppressing activity and influence of the bottom-up stimulus-salience evaluation mechanism, to support and prioritise goal-directed processes and behaviour. Consequently, it may be particularly useful for ABM to target and strengthen goal-directed inhibitory control over processing of task-irrelevant threat cues.

ABs towards and away from threat on attentional tasks may reflect the motivational priorities of the individual in that particular situation (e.g., to detect, monitor or avoid threat; or focus on task-related goals), which in turn may depend on state and trait influences (e.g., bottom-up bias from threat-salience evaluation system, top-down attention control, anxiety level, symptom profile, distress tolerance) and task-related and situational factors (e.g., task demands, threat severity, external stressors). Thus, ABs in orienting to threat may reflect imbalance between bottom-up and top-down systems involved in threat processing, without necessarily playing a primary causal role in anxiety.

A potential limitation of the framework is that it may seem relatively unconstrained, as it identifies multiple interlinked bottom-up and top-down cognitive functions in threat processing. This conceptualisation echoes the emphasis in cognitive-neuroscience research on interconnectivity and mutual influences among multiple brain networks. Its resulting flexibility may make it more difficult to evaluate, compared with cognitive models which propose that anxiety is primarily caused by a single cognitive bias (e.g., an automatic AB towards threat, reflected by spatial orienting). However, the latter view may be inaccurate and the present framework may be useful in providing a context for developing and evaluating interventions, by focusing more on modifying interactions between bottom-up and top-down systems. Further research is required to clarify the relationships between the component functions in the framework, given that understanding of precise nature of these inter-relationships is incomplete.

To advance progress, studies which evaluate treatments for anxiety should indicate the theoretical rationale underlying the intervention. Thus, studies assessing the effect of ABM-threat-avoidance training on anxiety should explain why this is expected to have long-term therapeutic benefit, given that this is disputed. For example, threat-avoidance is not consistently associated with low trait anxiety (Bar-Haim et al., 2007) and is sometimes found in anxiety disorders (e.g., Eldar et al., 2012; Salum et al., 2013; Waters et al., 2014).

Distinctions between bottom-up and top-down spatial orienting and inhibitory control processes have implications for ABM. Interventions such as ABM-threat-avoidance training, which focus on modifying automatic orienting towards threat without actively promoting engagement of cognitive control processes, may have relatively weak or inconsistent effects on improving goal-directed inhibitory control over threat processing. Instead, interventions that actively engage an integrated cognitive control system, which coordinates multiple top-down functions, may be more effective in normalising imbalance in top-down and bottom-up systems involved in threat processing, than those which target a single cognitive bias. For example, enhanced ABM-positive-search training aims to encourage active, flexible and sustained goal-directed attention search for positive and nonthreat information, while strengthening top-down inhibitory control over processing of threat distractors. While it explicitly trains attention search for positive versus negative stimuli (hence, is considered a variant of ABM training), it is not process-pure. For example, it engages multiple top-down functions during repeated exposure to threat cues, and may have benign widespread effects on processing by reducing the dominating influence of automatic threat-salience evaluation processes on other bottom-up and top-down cognitive functions. Nevertheless, a theory-driven multi-function treatment

approach, guided by models of anxiety, attention and cognitive control, may provide a useful step towards developing more effective treatments which can be delivered easily and inexpensively to large numbers of anxious individuals.

## Appendix

List of contents.

1. AB and ABM: Experimental methods and effects of ABM on anxiety
  - 1.1. Methods used in assessing AB
  - 1.2. Methods used in ABM training
  - 1.3. Therapeutic effectiveness of ABM
2. Diverse cognitive views of the role of attention in anxiety
  - 2.1. Automatic and strategic schema-based processing in anxiety (Beck & Clark, 1997; Beck, Emery & Greenberg, 1985)
  - 2.2. Direction of AB towards versus away from threat depends on trait anxiety (Williams et al., 1988, 1997), and task-related effort can sometimes suppress anxiety-related AB to threat
  - 2.3. Evolutionary function of nonconscious threat evaluation processes (Öhman, 1993, 1994)
  - 2.4. Anxiety stems from negative beliefs and poor self-regulatory executive function (Wells & Matthews, 1994)
  - 2.5. Four-factor theory: anxiety depends on four sources of information influenced by cognitive biases (Eysenck, 1997)
  - 2.6. Bias in automatic threat evaluation underlies trait anxiety and initial AB to threat, which may be followed by strategic avoidance (Mogg & Bradley, 1998)
  - 2.7. Trait negative affectivity and poor effortful control contribute to AB and risk of anxiety (Derryberry & Rothbart, 1997; Lonigan, Vasey, Phillips & Hazen, 2004)
  - 2.8. AB to threat in anxiety depends on automatic threat evaluation and is sometimes suppressed by task-related effort (Mathews & Mackintosh, 1998)
  - 2.9. Difficulty in disengagement of attention from threat in anxiety (Fox et al. 2001)
  - 2.10. Attention control theory: Anxiety impairs goal-directed attention and increases stimulus-driven attention (Eysenck et al., 2007)
  - 2.11. Multiple dysfunctions in threat processing may underlie anxiety (Bar-Haim et al., 2007)
  - 2.12. Three components of AB in anxiety: Facilitated attention, disengagement difficulty, and avoidance (Cisler & Koster, 2010)
  - 2.13. Overview of diverse views of cognitive mechanisms in anxiety
3. Models of attention and executive control systems
  - 3.1. Automatic detection and controlled search (Schneider & Shiffrin, 1977)
  - 3.2. Spotlight model of attention (Posner & Petersen, 1990)
  - 3.3. Biased-competition model of attention (Desimone & Duncan, 1995)
  - 3.4. Stimulus-driven and goal-directed attention (Corbetta & Shulman, 2002)
  - 3.5. Selective attention in perceptual and cognitive control processes (Lavie, 2005)
  - 3.6. Petersen and Posner's (2012) updated model of attention
  - 3.7. Unity-diversity model of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000)
  - 3.8. Diamond's (2013) framework of executive functions
  - 3.9. Multiple demand system (Duncan, 2010)
  - 3.10. Individual differences in attention and cognitive control

4. Integrative framework
  - 4.1. Core components of framework
  - 4.2. Cognitive correlates of anxiety
  - 4.3. Cognitive mechanisms contributing to anxiety
    - 4.3.1. Bottom-up stimulus-salience evaluation processes
    - 4.3.2. Bottom-up and top-down attention orienting
    - 4.3.3. Cognitive control processes
  - 4.4. Mechanisms and variables influencing ABs in orienting to threat
    - 4.4.1. Mechanisms underlying ABs on spatial attention tasks
    - 4.4.2. Time-course of ABs in orienting: Initial orienting, maintained attention, threat avoidance
    - 4.4.3. Influence of symptom profile on ABs in orienting
    - 4.4.4. Influence of stressors on ABs
    - 4.4.5. Influence of trait attention control on ABs
    - 4.4.6. Temporal instability of ABs in orienting
    - 4.4.7. Influences of other experimental variables on AB measurement
  - 4.5. Motivational and goal-related functions of ABs in orienting
  - 4.6. Do ABs in orienting to threat predict treatment outcome in anxiety?
5. Implications for ABM
  - 5.1. ABM-threat-avoidance training
  - 5.2. ABM-positive-search training
  - 5.3. Other novel ABM training methods
  - 5.4. Do different mechanisms underlie effects of ABM-threat-avoidance and ABM-positive-search training?
  - 5.5. Role of exposure
  - 5.6. Should ABM-positive-search training be construed as ABM-threat-avoidance training?
  - 5.7. Does the anxiolytic effect of ABM training depend on its effectiveness in reducing AB to threat?
  - 5.8. Summary of proposals relevant to ABM research
6. Related issues
  - 6.1. ABs in other conditions
  - 6.2. Interpretation bias modification in anxiety
7. Concluding comments

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