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ORIGINAL PAPER

Training Meta-Awareness to Modify Attentional Dyscontrol

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Abstract

Objectives We tested a brief computerized mental training intervention grounded in mindfulness principles – Attention Feedback Awareness and Control Training (A-FACT). A-FACT is designed to train meta-awareness of, and thereby greater self-regulatory control over, (biased) attentional processing of emotionally salient information.

Methods We studied $N = 58$ trait anxious adults ($M = 24$, $SD_{age} = 3.25$ years old; 72.4% female), among whom we expect to observe dyscontrol over attentional processing of threatening or anxiety-provoking information.

Results We found that (1) relative to an active placebo condition, participants randomized to A-FACT demonstrated higher levels of meta-awareness of biased attention; (2) relative to active placebo, A-FACT led to greater control of overt (eye movement) attention including reduced overt bias toward threat and degree of trial-to-trial temporal variability of overt attentional processing; and (3) degree of meta-awareness post-training was significantly associated with greater attentional control at post-relative to pre-training.

Conclusions Findings may have implications for mental or cognitive training technologies grounded in mindfulness principles and, more specifically, for the study of meta-awareness, attentional dyscontrol, and mental health.

Keywords Attention bias · Cognitive bias modification · Mental training · Meta-awareness · Mindfulness · Overt attention

There is a growing interest in the development and evaluation of mental training technologies to modify cognitive and, in particular, attentional biases (AB) implicated in common mental health problems such as anxiety (Kruijt and Carlbring 2018; MacLeod and Clarke 2015; Mogg et al. 2017; Van Bockstaele et al. 2014). Broadly, this research has been motivated by the potential therapeutic efficiency and specificity of process-focused training-based interventions targeting cognitive biases. Yet, to date, a very limited number or approaches to such training have been explored (Clarke et al. 2014; Hallion and Ruscio 2011; Koster and Bernstein 2015; MacLeod and Clarke 2015; Van Bockstaele et al. 2014), and a debate regarding the conceptual premise and therapeutic efficacy of the predominant training paradigm targeting AB is ongoing (e.g., Cristea et al. 2016; Hallion and Ruscio 2011; Kruijt and Carlbring 2018). Modification of AB has focused on attention bias modification training (Bar-Haim 2010; MacLeod and Clarke 2015; MacLeod et al. 2002), developed to implicitly condition attention, typically away, from some set of motivationally relevant stimuli (e.g., threat among anxious individuals). The effects of attention bias modification training, as tested in several meta-analyses to date, are mixed and, at best, small to moderate in magnitude (hedges g: 0.3–0.4), with limited evidence of transfer of these effects to stimuli and tasks beyond those that were explicitly trained (Everaert et al. 2015), or on psycho-behavioral correlates and outcomes (see Clarke et al. 2014; Hallion and Ruscio 2011; Koster and Bernstein 2015). In fact, recent papers have even rebranded the decades-old, standard administration of the dot-probe task that had previously served as the placebo control condition against which attention bias modification training was tested, as an "active intervention condition" named "attention control training." This occurred after the placebo control – simple dot-probe task administration – outperformed attention bias modification training (Lazarov et al. 2018).

Other disciplinary perspectives, therapeutic approaches, and training technologies may help guide novel approaches to mental training interventions targeting cognitive biases (Ding et al. 2014; Lustenberger et al. 2016; Ziegler et al. 2019). Specifically, translating mindfulness principles and practices to training technologies may be particularly

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promising. Indeed, mindfulness entails mental training practices and interventions designed to have a variety of salutary and curative effects by means of targeting and training attention and awareness of present moment experience, from moment-to-moment in time. Grounded in work on mindfulness over the past two decades (Bernstein et al. 2019b), intervention methods sensitive to and capable of targeting attentional processing of emotional information expression, as a dynamic process from moment-to-moment in real time, may be one important element of novel approach and technology to target AB (Bernstein and Zvielli 2014). To do so, training may specifically target *meta-awareness* of momentary expressions of AB. Indeed, meta-awareness is a meta-cognitive awareness of processes occurring in consciousness (e.g., thinking, feeling, sensing; Bernstein et al. 2015; Dahl et al. 2015; Flavell 1976; Jankowski and Holas 2014; Schooler 2002). Notably, meta-awareness is thought to be a primary meta-cognitive mechanism through which mindfulness training enables monitoring and thereby regulation of various internal states and mental processes (Analayo 2003; Bernstein et al. 2015, 2019a; Dunne et al. 2019; Segal et al. 2013). It has, however, not been a target of cognitive bias modification or related training interventions. Moreover, several studies documented the effect(s) of extended and brief mindfulness interventions on attentional processes and found that mindfulness intervention led to reduced attentional biases to negative stimuli (Garland and Howard 2013; Vago and Nakamura 2011), as well as significant improvement in sustained attention (Chambers et al. 2008; Jha et al. 2007), attentional control (Jha et al. 2007; Wenk-Sormaz 2005), and attentional selection (Jensen et al. 2012; Jha et al. 2007). In addition, recent findings suggest that mindfulness intervention strengthens working memory functions by maintaining and refreshing task set and capacity to manipulate information in working memory (e.g., Jha et al. 2019).

Accordingly, Bernstein and Zvielli (2014) developed *Attentional Feedback Awareness and Control Training (A-FACT)*. A-FACT delivers personalized real-time feedback on moment-to-moment or trial-level expressions of AB or attentional dyscontrol. Through real-time feedback, A-FACT was designed to train meta-awareness of momentary expressions of AB (i.e., meta-awareness of attentional bias (MAB)). MAB is hypothesized to enable self-regulatory control of (biased) attention and/or maladaptive behavior driven by biased attention (Ansorge et al. 2011; Chambers et al. 2008; Fox and Christoff 2014; Koivisto et al. 2009; Moore and Malinowski 2009; Teasdale et al. 1995). Training meta-awareness is thus hypothesized to short-circuit "downstream" processes driven by otherwise unmonitored and uncontrolled AB. Real-time feedback on attentional expression, specifically, was selected in light of (1) the core principles of cybernetics and self-regulatory theory – or the necessity of regulatory systems for feedback regarding current (so as to compare to a desired) state (i.e., monitoring-for-regulation function Carver and Scheier 1981) – and (2) documented effects of bio- and neuro-feedback on self-regulatory control over well-rehearsed, automatic, and typically unmonitored internal processes such as biased or dysregulated attentional allocation (e.g., Davidson et al. 1986; Sepulveda et al. 2016; Stoeckel et al. 2014). A-FACT uses real-time feedback to train meta-awareness in a way that is functionally similar to how mindfulness meditation may be used to train meta-awareness of biases of attention as they unfold from moment-to-moment in time. To be clear, however, in the present study, we are seeking to narrowly and specifically target meta-awareness of attentional dysregulation. We are not training mindfulness nor are we seeking or able to train various processes that characterize mindfulness such as attitudes of mindful awareness (e.g., acceptance).

There is a preliminary randomized control experimental evidence for the therapeutic utility of A-FACT. In the first empirical test, among anxious adults, A-FACT led to reduced levels of covert AB to threat and a faster rate of emotional recovery following an anxiogenic stressor relative to an active placebo control condition (Bernstein and Zvielli 2014). More recently, among anxious adults, an advanced version of A-FACT led to significantly reduced levels of AB toward and away from threat, a lesser degree of temporal variability of biased attentional processing of threat, as well as reduced emotional reactivity to an anxiogenic stressor relative to an active placebo control condition (Zvielli et al. 2016a). In the present study, we thus address two critical limitations in extant work on A-FACT specifically and mental training targeting meta-awareness as a means to enable control more broadly: (1) We do not yet know whether A-FACT indeed trains MAB and thereby leads to regulation of attentional processing of emotional information (e.g., threat), and (2) likewise, we do not know whether A-FACT impacts not only covert attentional dysregulation quantified through trial-level behavioral reaction time data but also overt attentional dysregulation quantified through tracking or measurement of eye movement. Below, we relate to these two key limitations and respective foci of the present study.

First, although A-FACT was designed to target meta-awareness of attentional dysregulation to enable cognitive/attentional control, no such test has been conducted to date. This is because, until recently, there was no methodology or computational approach to quantify MAB with psychometric rigor. Accordingly, Ruimi et al. (2018) developed a means to quantify MAB – the probe-caught meta-awareness of bias task (PC-MAB). They integrated probe-caught sampling methods (Smallwood et al. 2007), signal detection theory (Galvin et al. 2003; Maniscalco and Law 2012), and multilevel modeling. Probe-sampling methods, used to study meta-awareness of mind wandering (Smallwood et al. 2007), were applied to estimate real-time "subjective" AB, concurrent with the repeated trial-level expressions of (biased) attentional expression in the dot-probe task. Then, trial-level AB scores (Zvielli et al. 2015) were applied to estimate trial-level "objective" AB scores. Finally, signal detection theory, applied in earlier work on awareness and meta-cognition (Galvin et al. 2003; Maniscalco and Law 2012), was applied to empirically contrast the objective and subjective estimates of AB. In doing so, signal detection quantifies momentary expressions of MAB at the trial-level as the agreement between these trial-level estimates. Furthermore, to permit an estimation of individual differences in the levels of MAB across time (i.e., across trial-level estimates of momentary MAB), a single second-level parameter, based on signal detection theory, was calculated – the diagnostic odds ratio (i.e., *DOR*, see method section for further explanation). DOR is the ratio of the odds of "disease" (AB in the context of the present study) in test positives relative to the odds of "disease" (AB) in test negatives and thus reflects capacity of MAB at a subject level. They applied this approach to cognitive-experimental laboratory data among daily smokers, known to exhibit biased attentional processing of reward-related (drug) cues in addiction (Field et al. 2014; Pergamin-Hight et al. 2015; Wetherill et al. 2014; Zvielli et al. 2015).

Using this new methodology to quantify MAB, Ruimi et al. (2018) reported three key findings: (1) evidence of the capacity for individual differences in MAB; (2) momentary MAB was most likely observed in the event of the most extreme micro-expressions of biased attentional processing; and (3) momentary micro-expressions of biased attention *without* MAB were more likely followed by attentional dysregulation, whereas momentary micro-expressions of biased attention *with* MAB were more likely followed by more balanced attentional expression or greater attentional control. These initial findings document that people may have the (potential) capacity for MAB and that MAB may in part serve a monitoring-for-control function on attentional processing of emotion or motivationally relevant information important to mental (ill) health. These findings are consistent with the premise of targeting MAB as a means of modifying attentional dysregulation (via real-time feedback). A critical next step in this line of research is to test whether MAB is malleable, whether A-FACT indeed impact levels of MAB and whether MAB putatively trained via real-time feedback leads to or is linked to modification or regulation of dysregulated attentional processing of emotional information (e.g., threat among anxious adults).

Second, the effects of A-FACT on attentional dysregulation have been limited to covert attention quantified by behavior responding to the dot-probe task (trial-level response time data) (Bernstein and Zvielli 2014; Zvielli et al. 2016a, b). Yet, covert and overt attentional processes interact (Corbetta et al. 1998; de Haan et al. 2008; Hoffman and Subramaniam 1995; Posner 1980) and, together, underlie biased information processing (Amir et al. 2016; Armstrong and Olatunji 2012; Derakshan et al. 2009; Gerdes et al. 2008; Price et al. 2016; Robinson and Irwin 2016). Accordingly, behavioral evidence has demonstrated a strong link between covert and overt attentional processes (Hoffman and Subramaniam 1995); neuroimaging studies have documented shared neural substrate (de Haan et al. 2008). Likewise, measurement of overt attentional dysregulation has a significant methodological advantage relative to covert attention. Overt attention is quantified by continuous tracking of eye movement, from moment-to-moment, within, and across trials, whereas, to date, covert attention has been inferred from a single behavioral response measured upon termination of each task trial (e.g., upon presentation of a probe in the dot-probe task) or aggregated across a block of trials. Thus, an important next step in this line of research is to test whether, as theorized, A-FACT reduces *overt* attentional dysregulation and whether the degree of meta-awareness of covert attention, targeted by A-FACT, predicts or is related to increased regulation of overt attention (i.e., how we actually look at visual stimuli).

We therefore hypothesized that relative to an active placebo control condition, A-FACT would lead to the following: (1) elevated levels of MAB at post-training (i.e., via probe-caught sampling of dot-probe attention task and signal detection theory analysis; Ruimi et al. 2018)); (2) reduced overt attentional dysregulation at post-relative to pre-training (i.e., via eye-tracked latency to terminate a fixation on a visual stimulus and initiate a saccade to the probe; Amir et al. 2016). Likewise, we predicted that (3) the greater the degree of MAB following A-FACT, the greater the degree of reduced overt attentional dysregulation at post-relative to pre-training; moreover, we expected that this effect would be specific to the A-FACT condition and not among the active placebo control condition.

Method

Participants

From a university community in Israel, 61 high-anxious (State-Trait Anxiety Inventory (STAI) – *trait* anxiety scores $\geq$ 39; (e.g., Derakshan et al. 2009) young adult participants ($M(SD)$ = 24.0(3.25) years old, range$_{age}$ 19–40; 72.4% female) were recruited, where 29 were randomized to the A-FACT condition and 32 to an active placebo control condition. However, we did not succeed to acquire intact eye movement data for three participants (one A-FACT, two controls). Thus, analyses are reported among $N = 58$ (28 A-FACT, 30 controls). Potential participants were excluded on the basis of the following criteria: (a) impaired eyesight (uncorrected); (b) lack Hebrew-language reading and speaking fluency; or (c) current psychopharmacological treatment for anxiety or depression due to possibility that these agents may threaten the internal validity of the study by impacting estimates of attention bias and responsiveness to training. The ethnic/religious composition of the sample was 83.1% Jewish, 1.7% Muslim, 6.8% Druze, 3.4% Christian, and 5% other – a relatively representative sample relative to regional population norms in Israel where these data were collected (Israel Central Bureau of Statistics 2018). The study was approved by the University of Haifa's Committee on the Ethical Conduct of Human Subjects Research.

Procedures

Overview

There were (a) two conditions (A-FACT vs. control), (b) one pre- and one post-training measurement of AB, and (c) one post-training measurement of MAB (see Fig. 1). The present data used to compute MAB and overt attention were collected as part of a published parent study of A-FACT and covert (behavioral reaction time) attentional dysregulation (Zvielli et al. 2016a). The computational methodology to quantify MAB objectively using signal detection analysis of probe-sampling method data, as well as to quantify overt attentional dysregulation via eye movement data from a dynamic process perspective, is a recently methodological advance (Amir et al. 2016; Ruimi et al. 2018). These methods were not available at the time that the parent study was published. Accordingly, these MAB and overt attention data are novel and not heretofore published in any format (Fig. 2).

Pre-training Assessment

Potential participants completed the pre-session trait anxiety section of the State-Trait Anxiety Inventory (STAI;

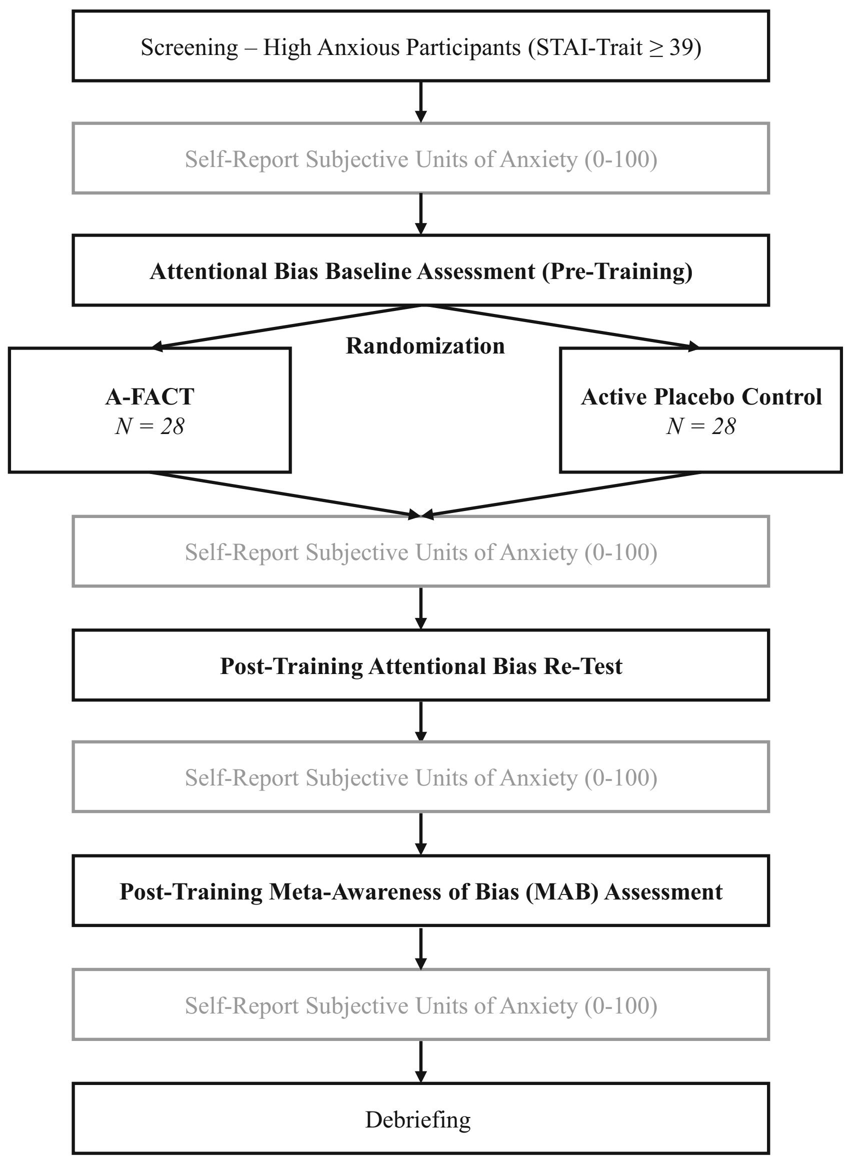

Fig. 1 Study overview

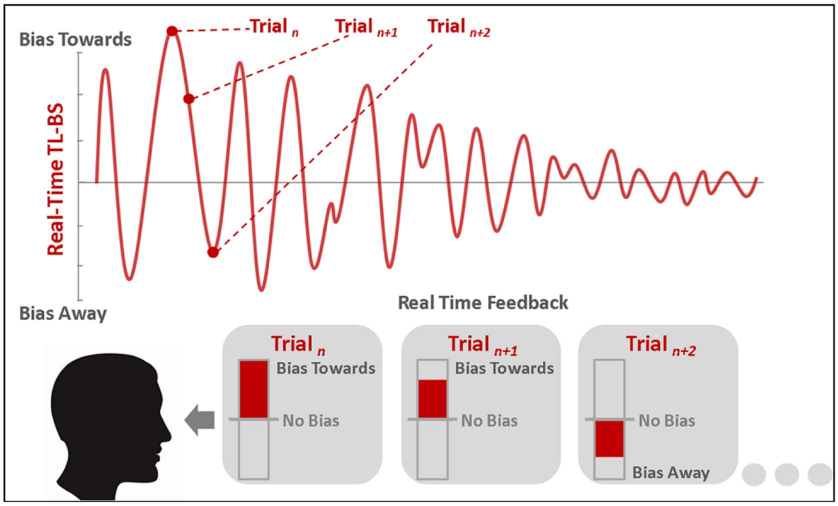

Fig. 2 Real-time feedback on attentional bias (A-FACT) based on real-time trial-level bias score methodology (reprinted from "Targeting Biased Emotional Attention to Threat as a Dynamic Process in Time: Attention Feedback Awareness and Control Training (A-FACT)" by A. Zvielli, I. Amir, P. Goldstein, & A. Bernstein. *Clinical Psychological Science, 4*(2), 287–298. Reprinted with permission). Real-time feedback is presented immediately following each trial-level bias expression, i.e., trial n emotional stimulus > response (RT) > real-time trial-level bias scores computation > real-time feedback delivery > trial $n+1$…Trial $n+2$…

Spielberger et al. 1983). The identified subsample of high-anxious participants then attended a single laboratory session. Upon arrival at the laboratory, participants provided a rating of their present-moment state anxiety in subjective units of anxiety (SUA; 0 = *no anxiety* to 100 = *extreme anxiety*). The experimenter, blind to condition, told participants that instructions would appear on the monitor over the course of the experimental session. Before beginning the computer tasks, the eye tracking software was calibrated by asking participants to follow a red dot to five locations on the display. Participants then completed the visual emotional dot-probe task (MacLeod et al. 1986) to measure pre-training levels of AB to threat.

Randomization to Condition

Eligible participants were then randomized to either the (1) Attentional Feedback Awareness and Control Training (A-FACT) condition or (2) active placebo control condition. All participants were told that "The computer has tested the way you allocate your attention, and found that your attention is affected by threatening stimuli." Participants were not informed as to the direction(s) (toward or away from threat) or the magnitude of their AB nor were they told about covert and overt indices of their attention.

A-FACT Condition

In the A-FACT condition, participants were instructed that they would next complete a task similar to the one they had just completed (pre-training emotional dot probe) but which is designed to reduce AB or the degree to which their attention is influenced by threat pictures. Participants were told that they would receive feedback regarding their allocation of attention. Participants were then introduced to the A-FACT feedback scale. Participants were told that feedback would be presented following occasional trials and that each feedback stimulus (reflecting "the degree to which their attention was influenced by a threatening picture") is related to the single immediately preceding trial only (for computation of personalized feedback, see Zvielli et al. 2016a). Participants were instructed to try to learn from the feedback in order to reduce their AB. Additionally, they were instructed that they were, again, to respond to the location of probe as quickly and accurately as possible.

Participants in the A-FACT condition completed 2 training blocks (counter-balanced), 100 trials/block, composed of 20 incongruent trials, 20 congruent trials, and 60 neutral trials, randomly distributed (no contingency) across each block, and thus up to 40 feedback trials were delivered per block. Two additional buffer neutral trials preceded each block, as in the dot-probe procedure at pre-training. The difference between the first and second training blocks was the set of stimuli presented – two unique sets of stimuli were used, one per training block. Participants received a 3-min break between training blocks. Neither of the training sets of stimuli included threat-neutral stimulus pairs from the testing set administered at pre-training and post-training assessments of AB.

Personalized Feedback: Delivery and Presentation

Please see Zvielli et al. (2016a) for details regarding the real-time, trial-level feedback procedure. Briefly, personalized feedback was delivered with respect to the specific threat categories (i.e., attacking dogs, attacking snakes, violence, weapons, angry faces) for which each participant demonstrated dominant AB at pre-training. Reaction time on neutral trials was used as an empirical reference to determine the degree to which each participant's reaction time on each specific congruent or incongruent trial differed from their neutral trial and therefore whether and to what degree AB was expressed on each individual congruent/incongruent trial. To enhance the accuracy of trial-level AB and thereby real-time feedback on trial-level AB, in the current A-FACT algorithm, the neutral trials reference was updated using a "running mean" of the neutral trial reaction times over the course of training. To increase specificity, accuracy, and simplicity for the participant to interpret and apply the trial-level feedback, each participant received only one form of feedback (either toward threat or away from threat) as a function of her/his dominant bias "direction" (toward or away) at pre-training. Each feedback scale stimulus was presented for 3 s, followed by 1.5 s of a blank screen preceding the next trial fixation cross. Following feedback, a random number of either one or two neutral trials were presented prior to the presentation of the next congruent/incongruent trial to prevent predictability of feedback presentation and help ensure task engagement on subsequent congruent/incongruent trial following a congruent/incongruent feedback trial.

Active Placebo Control Condition

Identical to the A-FACT condition, participants were instructed that they would next complete a task similar to the one they had just completed (pre-training emotional dot probe) but which is designed to reduce bias or the degree to which their attention is influenced by threat pictures. Participants were instructed that their task is again to respond to the location of probe as quickly and accurately as possible. Control condition participants completed an additional dot-probe task, identical to the pre-training dot probe. Task duration, the number of congruent, incongruent, and neutral trials, and stimuli sets were identical to the A-FACT procedure.

Post-Training Emotional Dot Probe: Attentional Bias Retest

Following the training phase, participants were asked again to provide a rating of subjective units of anxiety (SUA; 0 = *no anxiety* to 100 = *extreme anxiety*). Then, all participants again completed the emotional dot-probe task, identical to the pre-training task. At retest, participants were given the same task instructions. A-FACT participants were informed that this time they would not receive feedback during the task. Pre- to post-training effects of A-FACT, relative to placebo control, were tested with respect to the personalized stimulus categories on which participants' AB were estimated at pre-training and for which feedback and placebo control were delivered.

Post-Training Meta-Awareness of Bias (MAB) Assessment

Following AB retest post-training, participants were asked again to provide a rating of subjective units of anxiety (SUA; 0 = *no anxiety* to 100 = *extreme anxiety*). Then, participants in both groups completed the MAB assessment. MAB was measured only post-training because a pre-MAB measure could threaten the internal validity of the design by inadvertently leading to cueing or indirect training of MAB simply via probes of MAB and not via real-time feedback. Finally, following the MAB assessment, participants were asked to provide a rating of subjective units of anxiety (SUA; 0 = *no anxiety* to 100 = *extreme anxiety*). The entire procedure lasted approximately 90 min.

Measures

The State Trait Anxiety Inventory (STAI; Spielberger et al. 1983)

The STAI entails two 20-item scales, measuring state ("How do you feel right now?") and trait ("How you generally feel?") anxiety. For the purpose of the current study, we only used the trait scale of the STAI to identify subsample of high-anxious participants. The trait scale has demonstrated sound internal consistency ($\alpha = 0.86$–.95) in diverse populations, and the trait STAI 30-day test-retest reliability is strong ($\alpha = 0.71$ to 0.75; Spielberger et al. 1983). The STAI was translated from English to Hebrew and then translated back by a separate party using structured guidelines (Brislin 1970).

Subjective Units of State Anxiety (SUA)

Participants were asked to rate their current levels of anxiety (i.e., experience samples 0–100 of anxiety level) at four time points: baseline, post-training, post-retest, and post-meta-awareness measurements. A total of state anxiety scores were calculated (i.e., average of four time-point reports).

Attentional Bias Assessment

The visual emotional dot-probe task (MacLeod et al. 1986) was used to measure AB to threat at pre-training, during the two training/placebo control blocks and again at post-training. Participants were presented with a fixation cross (500 ms), followed by 100-ms blank screen, followed by two stimuli presented simultaneously for a duration of 500 ms – one stimulus was presented to the left of the fixation cross and the other to the right, one of which was immediately replaced by a small black probe (50% per side). Participants were instructed to first focus their gaze on the fixation cross, and then, as quickly and accurately as possible, to press one of two (left or right) response box buttons corresponding to the location of the probe. A random interval of 500–1500 ms preceded the next trial. On incongruent trials, the probe appeared in the location of the neutral stimulus, whereas on congruent trials, the probe appeared in the location of the threat stimulus. Additional trials included two neutral stimuli.

Stimuli

Threat and neutral stimuli were a combined set from the International Affective Pictures System (Lang et al. 1999) and additional images (18 IAPS images, 12 selected images; Bernstein and Zvielli 2014), digitally resized to 8.5 cm width × 6.5 cm width-height (Bardeen and Orcutt 2011; Bradley et al. 2003; Mikels et al. 2005). Distance between each pair of stimuli was 5.6 cm (see Bernstein and Zvielli (2014) for validation of study stimuli).

Apparatus

During the dot-probe task, eye movements were recorded using Tobii TX300 eye tracker (Tobii Technology Inc., 2010), at a sampling rate of 300 Hz. Eye movement data were filtered and analyzed into saccades and fixations by Tobii Studio using the velocity-threshold identification filter (default settings at 75-ms maximum gap length for interpolation, maximum time/angle between fixations for merging adjacent fixations at 75 ms/0.5º, fixations below 60 ms duration discard; Olsen 2012).

Meta-awareness of Bias (MAB) Assessment

Grounded in probe-caught thought sampling methods (Giambra 1995; Smallwood and Schooler 2006), participants were repeatedly probed regarding their attention, concurrent with the repeated trial-level expressions of (biased) attentional expression in the dot-probe task. Awareness probes were delivered on 25% of randomly selected trials (i.e., on 50 of 200 trials). Immediately following trial response, participants were asked to report whether one of the pictures in the last trial influenced their response ("During the last trial, was your attention influenced by one of the pictures?" (Hebrew: "בצעד האחרון, האם תשומת הלב שלך הושפעה מאחת התמונות?"). By contrasting indices of real-time subjective AB estimates (i.e., via probe-caught awareness samples) with real-time objective AB scores (i.e., via trial-level bias score expression), we were able to compute an objective index of MAB in real time (Ruimi et al. 2018) (see Data Analytic Approach section for a detailed description of MAB quantification).

Data Analyses

Response Time: Covert Attention

In the pre-training, two training blocks and post-training dot-probe tasks, 1.1% error-response trials (i.e., "left" response when probe appeared on the right, and vice versa) and 1.7% reaction time outliers (trial reaction time < 200 ms or > 1500 ms, trial reaction time > 3 *SDs* above or below participant's mean reaction time per trial type), were discarded based on a priori criteria for valid trial selection.

Eye Movement: Overt Attention

Fixations and saccades to the left/right stimulus/probe were counted if the fixation landed at least 1 horizontal degree outside the center of the display. Trials were omitted if one of two events occurred: (1) the participant was not fixated on the fixation cross during stimulus onset (*M(SD)* = 5.7%(5.3%) trials were omitted per participant) and (2) when a fixation was initiated in less than 100 ms following stimulus onset – as this is evidence of a premature fixation initiated prior to the capacity to process stimulus (*M(SD)* = 4.3%(2.7%) trials were omitted per participant) (Garner et al. 2006). The mean number of congruent or incongruent trials with EMs, from stimulus onset to probe offset, in pre-training and post-training, was *M(SD) = 56.41(16.48)%* and *M(SD) = 55.86(19.53)%*, respectively, out of the total 100 possible trials.

Trial-Level AB Scores Computation of Overt AB

In light of the now well-documented low reliability of traditional aggregated mean computations of AB (Rodebaugh et al. 2016; Zvielli et al. 2015), we focused on *latency to probe* as an index of overt AB to threat as per (see Amir et al. 2016). Latency to probe reflects the time to the first saccade that occurred after probe onset, in the direction of the probe location. Saccade direction was used because, whereas participants' peripheral vision can correctly detect the location of the probe (without a novel fixation, as occurred in some trials), an exogenous saccade in the direction is typically initiated (Theeuwes et al. 1998). Latency to probe was chosen, as it depicts the overt attentional process that parallels the covert attentional process on which A-FACT provides feedback – latency to respond to the appearance of the probe. As Amir et al. (2016) illustrated, this specific attentional action reflects the critical window of overt and covert attentional behavior on the dot probe – wherein participants need to shift (spatial) attention from the task-irrelevant stimulus to the (location of the) task-relevant probe (e.g., latency to terminate a fixation on task-irrelevant (threat) stimulus and initiate a saccade to the location of the task-relevant probe).

Latency to probe was calculated by subtracting the mean time to initiate a saccade to the probe on congruent trials from mean time on incongruent trials. On some trials, participants fixate on stimuli during stimulus presentation and no further within-trial fixations occurred (i.e., participants looked at the images but did not make a fixation to the probe). In these cases, to maximize the number of trials used, we imputed one of two possible trial-level values for latency to probe. If probe and fixation locations were congruent, reflecting that overt attention was already engaged at the location of the probe, the minimum possible saccade latency (i.e., probe onset time) value was imputed. If the location was incongruent, reflecting no orientation of overt attention to the probe location, the maximum possible latency value (i.e., probe onset time + trial's response time) was imputed.

To test group differences (A-FACT vs. active placebo conditions) in pre- to post-training levels of AB dynamics, we computed trial-level bias scores (Zvielli et al. 2015). Recent studies demonstrated convergent, incremental, known-group criterion, and predictive validity of the dynamic features of AB, in multiple tasks (e.g., dot-probe task, spatial cueing task), with respect to a variety of outcomes (Amir et al. 2016; Davis et al. 2016; Iacoviello et al. 2014; Yuval et al. 2017; Zvielli et al. 2016b). Furthermore, in contrast to poor reliability of traditional aggregated mean bias scores, key features of the temporal dynamics of AB (trial-level bias dynamics parameters) have demonstrated acceptable to excellent split-half reliability (Rodebaugh et al. 2016; Zvielli et al. 2015). Trial-level AB scores were computed by matching and then subtracting overt (latency to probe) attentional measures between temporally contiguous pairs of threat-neutral (i.e., either congruent or incongruent trials) trials by subject. Specifically, each threat trial (congruent/incongruent) was matched with a neutral trial that was as temporally as close as possible and no further than five trials following the threat trial. Importantly, this computation paralleled the algorithm underlying A-FACT trial-level measurement of AB and real-time feedback targeting covert AB (see Method Procedure above). To estimate AB toward or away per trial, on congruent trials, the congruent trial latency to probe was subtracted from the matched neutral trial latency to probe, whereas on incongruent trials, the matched neutral latency to probe was subtracted from the incongruent trial latency to probe.

Key Features of Temporal Dynamics of Overt AB: Trial-Level AB Parameters

To optimally estimate AB as a dynamic process in time, we used three of the five parameters reported in Zvielli et al. (2016a) and Amir et al. (2016): (1) mean trial-level bias score positive (i.e., *mean toward*) and (2) mean trial-Level bias score negative (i.e., *mean away*), reflecting individual differences in the degree to which the mean trial-level AB scores display AB toward (positive) and AB away (negative) from target stimuli, and (3) trial-level bias score variability (i.e., *variability*), reflecting the degree of temporal stability/variability in the expression of AB toward and/or away over time. The effects of A-FACT vs. active placebo control were tested on each trial-level AB score parameter for the personalized threatening stimuli categories for which the participant received, or would have received, feedback in A-FACT or control conditions, respectively.

Data Analytic Plan: Attentional Bias Modification

To test effects of A-FACT on overt trial-level AB parameters, we conducted a two-way mixed ANOVA per each trial-level AB parameter outcome. Dependent variables included the three trial-level AB parameters (mean toward, mean away, variability). Independent variables included the within-subject variable "time" ("pre-training," "post-training") and the between-subject variable "group" (A-FACT, control).

A Signal Detection Theory Computation of MAB

As per Ruimi et al. (2018), to quantify the agreement between subjective covert AB estimates (i.e., via answers to awareness probes) and objective covert AB scores (i.e., via trial-level bias scores), we matched subjective reporting of covert attention allocation with trial-level covert AB scores, on each awareness probe. We thereby computed true- and false-positive/negative rates (Galvin et al. 2003; Maniscalco and Law 2012). Trial-level MAB scores (i.e., true and false positives/negatives) were then aggregated across awareness probes and trials to compute a single indicator of MAB – the diagnostic odds ratio (DOR; i.e., the ratio of the odds of disease in test positives relative to the odds of disease in test negatives) (Glas et al. 2003). DOR has the unique advantage of a single indicator to estimate MAB by providing a valid representation of the participant's discriminatory performance and combines estimates of sensitivity and specificity. Importantly, DOR is independent of individual differences in the rate of objective trial-level micro-expressions of AB and thus well-suited to estimate sample and individual differences in MAB. The DOR is calculated as follows:

$$\mathrm{DOR} = \frac{\mathrm{TP}}{\mathrm{FP}} \Big/ \frac{\mathrm{FN}}{\mathrm{TN}} = \frac{\mathrm{TP}\cdot\mathrm{TN}}{\mathrm{FP}\cdot\mathrm{FN}}$$

DOR values range from 0 to infinity. Higher values indicate better discriminatory test performance (Glas et al. 2003) (e.g., DOR = 2 means that for a particular subject, the odds of (accurately) detecting AB when AB was objectively expressed (true positive) was twice the odds for (inaccurately) detecting AB in the absence of AB (false positive)) (see also Ruimi et al. (2018) for additional details).

Results

Preliminary Analyses

All analyses were run using IBM SPSS Statistics, Version 24.0 (2016) (two-tailed, critical $p = .05$). First, to rule out artifacts, and to examine whether randomization was successful respect to pre-training levels of each of the parameters of AB dynamics, we tested pre-training levels of AB among participants at baseline. In line with successful randomization, we found that for all trial-level AB parameters, there was no between-group difference at pre-training (mean toward, t (56) = −0.3, $p = 0.77$; mean away, t (56) = 0.36, $p = 0.72$; variability, t *(56)* = −1.00, $p = 0.32$); in addition, though not included in the current analyses, we also found no between-group difference at pre-training for peak positive (t (56) = −1.53; $p = 0.13$) and peak negative (t (56) = 0.25; $p = 0.19$). Likewise, there were no differences at pre-training between A-FACT participants that received feedback on AB toward (51.6% A-FACT participants) or away from threat (48.4% A-FACT participants) ($\chi2 = 0.75$; $p = 0.39$).

Meta-Awareness of Covert Biased Attentional Processing

To test whether A-FACT led to elevated levels of MAB at post-training, we calculated the DOR as a single indicator for MAB per participant. As predicted, participants in the A-FACT group ($M = 1.90$; $SD = 1.72$; range = 0.24 to 7.56; 67.9% DOR > 1) demonstrated higher levels of MAB than the active placebo control group ($M = 1.11$; $SD = 0.79$; 0.19 to 4.28; 48.5% DOR < 1) (t (36.56) = −2.23; $p = 0.03$), wherein DOR $\leq$ 1 represents no MAB and DOR > 1 represents some degree of MAB (Ruimi et al. 2018).

Overt Attentional Bias Modification

See Table 1 descriptive statistics on each trial-level AB parameter, by condition, at pre- and post-training. See Figure 3 for change trajectories of trial-level AB parameters by condition. We tested expected group differences in change trajectories of overt attentional latency to probe – reflecting AB toward (i.e., a shorter time to initiate a saccade to the target probe on congruent trial and longer time on incongruent trial) or away (i.e., longer time to initiate a saccade on congruent trial and shorter time on incongruent trial) from threat – on each of the trial-level AB parameters from pre-training to post-training/placebo. We began by examining change in overt AB toward threat. A significant time × group interaction was found for mean toward threat ($F(1.54) = 7.19$; $p = 0.01$; $\eta^2 = 0.118$). As predicted, contrasts of change trajectories indicated that A-FACT participants, but not controls, demonstrated a significant reduction in levels of mean toward from pre- to post-training ($F(1.26) = 12.32$; $p = 0.002$; $\eta^2 = 0.322$). Third, we tested the expected group differences on change trajectories reflecting overt AB away from threat. Although consistent with prediction in terms of its direction, the time × group interaction for mean away approached but did not reach significance ($F(1.54) = 3.25$; $p = 0.077$; $\eta^2 = 0.057$). Fourth, we tested the expected group differences on change trajectories of variability in AB. A significant time × group interaction was found for AB variability ($F(1.54) = 8.73$; $p = 0.005$; $\eta^2 = 0.139$). As predicted, contrasts of change trajectories indicated that A-FACT participants, but not controls, demonstrated a significant reduction in levels of AB variability from pre- to post-training ($F(1.26) = 9.37$; $p = 0.005$; $\eta^2 = 0.265$).

Association Between Meta-Awareness of AB and Overt AB Modification

We tested the associations between MAB (as measured via response times, i.e., covert) and change trajectories of overt AB (attentional latency to probe) on each of the trial-level AB parameters from pre- to post-training/placebo. First, as expected, the greater the levels of MAB, the greater the reduction of overt AB toward threat among the A-FACT group ($r = -0.51$; $p < .01$), but not among controls ($r = 0.01$; $p = 0.943$). Likewise, the greater the levels of MAB, the greater the reduction of overt AB away from threat among the A-FACT group ($r = 0.38$; $p = 0.059$), but not among controls ($r = -0.17$; $p = 0.374$); although the former association is relatively large in magnitude, the effect only neared significance. Although consistent with the predicted direction of the effect, the association between levels of MAB and change in overt AB variability approached but did not reach significance (A-FACT, $r = -0.34$, $p = 0.098$; control, $r = 0.07$, $p = .719$).

Discussion

We tested a brief mental training intervention grounded in mindfulness principles – Attention Feedback Awareness and Control Training (A-FACT) – to train meta-awareness of, and thereby greater self-regulatory control over, (biased) attentional processing of emotionally salient information (i.e., AB). Specifically, we examined three interrelated questions in this experimental laboratory intervention study of the effects of real-time feedback on meta-awareness and overt visual attentional processing of threatening information among trait anxious adults. First, we tested whether A-FACT may indeed, as designed, train MAB. We quantified MAB using the probe-caught meta-awareness of bias task (PC-MAB) (Ruimi et al. 2018). Briefly, we used signal detection to quantify momentary expressions of MAB at the trial level as the agreement between these trial-level estimates and estimated individual differences in the levels of MAB across time (i.e., across

Table 1 Descriptive statistics for overt trial-level bias scores parameters by group

Overt bias dynamics parameters	Group	Pre-training	Post-training	*N*
M(SD)				
Mean toward	A-FACT	54.46 (25.01)	40.50 (19.07)	*N* = 28
	Control	52.37 (27.08)	58.50 (43.95)	*N* = 30
Mean away	A-FACT	−50.05 (30.25)	−36.00 (17.62)	*N* = 28
	Control	−47.13 (31.06)	−49.37 (30.71)	*N* = 30
Peak positive	A-FACT	209.32 (146.35)	137.39 (69.43)	*N* = 28
	Control	161.73 (85.39)	181.87 (110.86)	*N* = 30
Peak negative	A-FACT	−190.61 (158.49)	−125.46 (80.50)	*N* = 28
	Control	−144.97 (101.66)	−168.47 (153.83)	*N* = 30
Variability	A-FACT	69.61 (35.59)	46.89 (22.11)	*N* = 28
	Control	60.97 (28.39)	65.33 (33.54)	*N* = 30

trial-level estimates of momentary MAB) by means of the signal detection diagnostic odds ratio. As predicted, relative to active placebo control, participants randomized to real-time feedback on biased attentional processing of threat demonstrated significantly higher levels of MAB.

Second, we examined whether A-FACT impacts not only covert attentional dysregulation (reaction time data) (Bernstein and Zvielli 2014; Zvielli et al. 2016a, b) but also overt attentional dysregulation quantified via continuous, high temporal resolution tracking of eye movement. Importantly, we focused on the critical and specific temporal and attentional window within each dot-probe trial wherein participants must shift attention from task-irrelevant visual images so as to locate, reorient, and respond to the task-relevant probe – i.e., the overt attentional process that most closely parallels, in time and function, the cognitive process of covert attention reflected by reaction time (Amir et al. 2016). As expected, A-FACT led to reduced overt AB toward threat (i.e., shortened latency to initiate a saccade to the target probe on congruent trials and longer time on incongruent trials) as well as a lesser degree of temporal variability of overt AB and stable attentional allocation to threatening information from trial-to-trial. Similar effects, but of a notably smaller magnitude, were observed with respect to overt AB away from threat. Importantly, this pattern of effects is consistent with that found for A-FACT on covert attentional dysregulation (Bernstein and Zvielli 2014; Zvielli et al. 2016a, b).

Third, we examined whether the degree of MAB that results from real-time feedback predicts the degree of attentional regulation or control that results from training. This is the first such test of the core functional salutary mechanism that led to the development of A-FACT (Bernstein and Zvielli 2014). Specifically, we tested the associations between MAB and change trajectories of overt attentional processing of threat

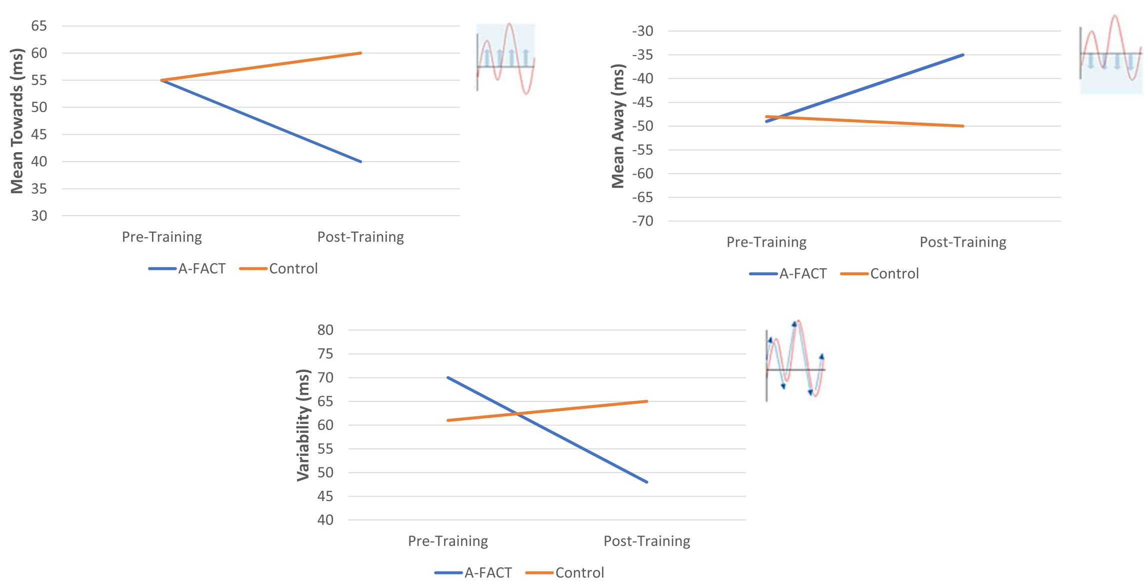

Fig. 3 Effects of A-FACT on overt attentional bias dynamics

from pre- to post-training by training condition. Findings were partially consistent with predictions. First, as predicted, the higher the degree of MAB following A-FACT, the less overt AB toward threatening information; this effect was relatively large in magnitude ($r = -52$). Critically, as predicted, this effect was moreover only observed among participants assigned to the A-FACT but not placebo condition. Second, as predicted, a similar effect was observed between MAB and degree of change in AB away from threatening information ($r = 38$), although this effect for AB away only neared significance, likely due to limited statistical power. Finally, inconsistent with prediction, the degree to which A-FACT led to MAB was not significantly related to the degree of change in variability of AB of threat. Again, although the magnitude of the latter null effect ($r = -34$) was moderate in magnitude, the analysis was underpowered. Overall, findings are largely consistent with the hypothesis that meta-awareness of biased attentional processing of emotional information (threat), trained through real-time feedback on covert attentional processing, may enable some degree of self-regulatory control over *overt* attentional processing of emotional information.

The present findings have a number of implications for basic and clinical study of attentional dysregulation and mental health. First, findings may have implications for cognitive bias modification targeting dysregulation of emotional attention in mental health (see McNally 2019 for a review). To date, few studies have tested the effects of any cognitive bias modification on overt attention via eye tracking. Arditte and Joormann (2014) found no effect on the aggregated mean overt AB or emotional reactivity. Conversely, Chen et al. (2015) found that attention bias modification training led to reduced levels of aggregated mean overt AB toward threatening stimuli, as well as anti-saccade cost, indicative of inhibitory attentional control facilitation. However, modification of AB following attentional bias modification was not related to change in attentional control. Lazarov et al. (2017) examined the efficacy of a gaze-contingent music reward training for social anxiety disorder, designed to reduce overt attentional dwelling on or promote strategic avoidance away from visual threat stimuli. Much like the A-FACT procedure (Bernstein and Zvielli 2014), participants were given real-time (trial-level) feedback contingent on their overt (eye movement) attentional processing (i.e., music when their gaze was focused an emotionally neutral rather than emotionally threatening face) over eight 20-min sessions, twice weekly over 4 weeks. They reported that, relative to controls (i.e., participants heard chosen music continuously throughout the task), real-time gaze-contingent feedback training led to (a) reduced dwell time on threat, and altered dwell time on socially threatening faces, and (b) greater reductions of symptoms of social anxiety disorder on both clinical-related and self-reported measures, as well as reduced social anxiety symptoms at 3-month follow-up. The present findings thus contribute to this emerging work targeting overt attentional processing of emotional information. Specifically, the present findings are noteworthy in that they demonstrate the capacity for real-time feedback to enable the regulation of overt attentional processing of threat among trait anxious adults.

Relatedly, the present findings point to meta-awareness or MAB as a potentially important salutary mechanism of action through which real-time feedback may operate and through which attentional dysregulation may be therapeutically targeted. Specifically, the present findings indicate that similar to meta-awareness of other mental processes (Dunne et al. 2019; Lutz et al. 2015; Schooler et al. 2011), training MAB via real-time feedback may provide a monitoring-for-regulation function. Indeed, training MAB may reduce dysregulated attentional processing directly by means of top-down executive control that actively inhibits exogenous attentional orienting toward or away from reward or threat cues (Bernstein and Zvielli 2014; Schooler et al. 2011). Specifically, the present findings suggest that MAB may serve a moment-to-moment internal feedback function regarding the allocation of (dysregulated) attention, thereby enabling top-down regulation or control of attentional processing (Mansell and Marken 2015). Alternatively or additionally, MAB may enable indirect regulation or control of attention by directly impacting other internal states that influence or subserve attentional processing. Thus, our findings indicate that MAB is likely malleable and may be targeted via interventions such as A-FACT and that this approach and training target may provide a novel means to therapeutically impact attentional dysregulation that has been implicated in a variety of mental health problems. More broadly, this approach and findings point to the potential utility of translating principles and practices of mindfulness for development of novel mental training technologies targeting dyscontrol and related biases of attention.

Observed effects of A-FACT on overt attentional processing of threatening information may also have notable conceptual implications for future research on executive or cognitive control and specific components of attentional dysregulation or bias. Specifically, we found that whereas A-FACT led to reduced levels of biased attention *toward* threat, similar effects were less robust (and not significant) with respect to biased attention *away* from threat. Real-time feedback is designed to work through the endogenous attention system, activating top-down/executive control processes. It has been argued that AB toward threat may be driven by exogenous (bottom-up) processes (e.g., Bishop 2007). Accordingly, it may be that with respect to threatening information, by training MAB, A-FACT may evoke endogenous system regulation of the exogenous system. Conversely, AB away from threat has been conceived as a later stage of processing, driven by the endogenous/executive control system, in which top-down processes drive avoidance of threatening stimuli (Cisler and Koster 2010;

Corbetta and Shulman 2002). Thus, it may be that attentional feedback creates a conflict within the endogenous/executive control system when feedback is given for avoidance of threat, thereby limiting the therapeutic effects of A-FACT on AB away from threatening information. Future research may examine whether a larger dose of A-FACT or attentional feedback in a different form or modality may more effectively promote therapeutic change in AB away from threat.

Limitations and Future Research

The present study has a number of limitations. First, participants were trait anxious adults recruited from a university community, and the sample size was relatively small. It is important that future study also examines the effects of A-FACT on MAB and covert and overt attention among clinical population groups, in addition to using a more statistically powered test, with a larger sample size. Second, the intervention was delivered once and in the lab. Effects beyond the lab and over time were not tested. Larger-scale clinical intervention studies may be one important next step. Third, MAB was only measured at post-training, limiting our capacity to infer causality of the intervention with respect to change in MAB. We made this design decision because pre-training measurement of MAB could threaten the internal validity of the design. Indeed, the probe-caught measurement methodology could inadvertently lead to cueing of, or unintended training of, MAB (Schooler et al. 2011; Smallwood and Schooler 2006). Fourth, this study examined the effects of A-FACT on overt AB dynamics when feedback was delivered on the real-time expression of covert AB. Future studies may directly test whether real-time feedback on overt AB similarly generalizes to the modification of covert AB. Such research may not only be clinically important but may help explicate important questions about attentional mechanisms underlying covert and overt AB. Fifth, it is important that future research also tests whether the documented effects of A-FACT on MAB or overt bias transfer to other tasks or related processes putatively are related to biased attentional processing (Everaert et al. 2015). Sixth, due to limited sample size and respective statistical power (Fritz and MacKinnon 2007), we were not able to formally test whether levels of or change in MAB mediate the effect of the A-FACT on overt bias but only to document that levels of MAB post-training were significantly related to change in overt bias following A-FACT. Finally, future work could test how A-FACT or a similar mental training targeting meta-awareness may perform relative to a meditation-based mindfulness practice with respect to meta-awareness broadly or MAB specifically as well as biased attentional processes.

In summary, the present study provides initial evidence for A-FACT as a means to target MAB and therefore to enable control of overt attentional dysregulation in response to emotional information. Beyond this study, the approach and findings may have implications for the potential to translate mindfulness principles and practices for the development of novel mental and cognitive training technologies.

Author Contributions All authors designed and executed the study, as well as assisted with the data analyses and writing of the manuscript. All authors approved the final version of the manuscript for submission.

Compliance with Ethical Standards

Conflict of Interests The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The research was approved by an Institutional Review Board of University of Haifa.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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