Targeting Biased Emotional Attention to Threat as a Dynamic Process in Time: Attention Feedback Awareness and Control Training (A-FACT)

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Abstract

Recent findings suggest biases of emotional attention (BEA) may be expressed dynamically, fluctuating from moment-to-moment between over-engagement and avoidance of emotional stimuli. We attempted to modify these temporal dynamics of BEA to threat among trait-anxious adults (N = 61) using Attention Feedback Awareness and Control Training (A-FACT). A-FACT is a novel intervention methodology that delivers real-time feedback to a person concurrent with her/his dynamic BEA expression. We found that relative to a placebo control condition, A-FACT led to significantly reduced: BEA dynamics *towards* and *away* from threat, temporal *variability* in BEA, as well as emotional reactivity to an anxiogenic stressor. Findings illustrate that BEA may be optimally conceptualized and quantified as a dynamic process in time; and that intervention methods sensitive to and capable of targeting BEA process dynamics in real-time – as in A-FACT – represent a promising new direction for cognitive bias modification research.

Targeting Biased Emotional Attention to Threat as a Dynamic Process in Time:

Attention Feedback Awareness and Control Training (A-FACT)

Preferentially attending to motivationally-relevant information in a flexible, context-sensitive and task-relevant manner is essential for adaptive responding to environmental demands, opportunities, and threat (Carretie, 2014; Vuilleumier, 2005). *Biases of emotional attention* (BEA), which result from dysregulation in this adaptive attentional mechanism, contribute to various forms of anxiety, mood and substance use disorders (Cisler & Koster, 2010; Field & Cox, 2008; Mathews & MacLeod, 2005; Shechner et al., 2012; Van Bockstaele et al., 2014). Accordingly, research has focused on the promise of therapeutically targeting BEA, and in particular, BEA to threatening stimuli as a means to target problems with anxiety (e.g., MacLeod & Clarke, 2015).

Experimental and clinical study of BEA modification has focused on Attention Bias Modification Training (ABMT; Bar-Haim, 2010; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; MacLeod & Clarke, 2015). The central premise of ABMT is to implicitly condition attention, typically away, from some set of motivationally-relevant stimuli (e.g., threat among anxious individuals). ABMT has been the subject of extensive research in recent years (e.g., Clarke, Notebaert, & MacLeod, 2014; Hallion & Ruscio, 2011; Heeren, De Raedt, Koster, & Philippot, 2013; Hertel & Mathews, 2011). The status of the effects of ABMT remains contentious and mixed. Whereas some meta-analyses have pointed to small but reliable effects (e.g., Beard, Sawyer & Hofman, 2012; Linetzky, Pergamin-Hight, Pine & Bar-Haim, 2015) other work has indicated that there is little evidence of ABMT efficacy (e.g., Mogoaşe, David, & Koster, 2014; Hallion & Ruscio, 2011). To advance the experimental and clinical science of BEA, researchers have called for developing additional approaches and methods in addition to ABMT (Clarke et al., 2014; Hallion & Ruscio, 2011; Heeren et al., 2013; Hertel & Mathews, 2011; MacLeod & Clarke, 2015; Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013; Mogoaşe et al., 2014). Accordingly, researchers are increasingly asking what BEA modification should aim to achieve, what mechanism(s) should be targeted in such modification, and how emerging ideas about the nature of BEA may help guide novel approaches to targeting BEA (Clarke et al., 2014; Heeren et al., 2013; MacLeod & Clarke, 2015; Mogoaşe et al., 2014)? Our primary aim in the present paper was to build on emerging perspectives in the study of BEA in order to propose and begin to test possible answers to these questions.

In the decades-old paradigm underlying cognitive-experimental tasks measuring BEA (e.g., modified-dot probe, spatial cueing, visual search), BEA has been conceptualized as a *static trait*. Accordingly, BEA was quantified by the aggregated mean of responding to one type of condition (e.g., incongruent/invalid trials) relative to responding to a second type of condition (e.g., congruent/valid trials). In contrast to this paradigmatic assumption, in Zvielli, Bernstein, and Koster (2014a), we proposed that BEA may be better described as a *dynamic process* expressed in fluctuating, phasic bursts, towards and/or away from motivationally-relevant stimuli from moment-to-moment. Accordingly, we applied a novel computational procedure estimating BEA concurrent with its repeated, real-time expression from trial-to-trial in time (Trial Level Bias Scores (TL-BS); see Figure 1) in dot probe task data. We found that BEA indeed demonstrated phasic bursts of differential attention over time and temporal variability in BEA towards *and* away from motivationally-relevant stimuli. Furthermore, we found that key features of the temporal dynamics of BEA (e.g., mean-, peak-, and temporal variability in BEA towards *and* away from motivationally-relevant stimuli) demonstrated significantly improved split-half reliability ($r_{\text{Spearman-Brown Prophecy}} = .47$ to .80) compared to near 0-levels of split-half reliability for traditional aggregated mean bias scores ($r_{\text{Spearman-Brown Prophecy}} = .11$; Schmukle, 2005; Waechter, Nelson, Wright, Hyatt, & Oakman, 2013; Waechter & Stolz, 2015); as well as incremental predictive validity, above and beyond traditional aggregated mean bias scores, in discriminating between phobics and healthy controls, and predicting daily smoking rate among deprived smokers.

In addition to basic science implications for better understanding BEA (see Zvielli, Bernstein, & Koster, 2014a for details), conceptualizing and quantifying BEA as a dynamic process may help guide novel cognitive bias modification (CBM) approaches to target BEA and its psycho-behavioral outcomes in three inter-related ways: (1) By helping to refine the aim and guiding the delivery of BEA modification – to target BEA as a *dynamic process in time* rather than an as a static, stable trait. (2) By quantifying modification of BEA with respect to change in its temporal dynamics rather than (aggregated mean) change of a static trait. (3) By targeting cognitive mechanisms that may affect BEA dynamics in time *and* that may modulate relations between BEA and maladaptive psycho-behavioral outcomes (e.g., threat-related bias and anxious arousal). Accordingly, we propose that an intervention methodology sensitive to and able to target BEA process dynamics in real-time may be a promising new direction for CBM.

Guided by these ideas, Bernstein & Zvielli (2014) developed a novel CBM intervention methodology targeting BEA dynamics – *Attentional Feedback Awareness & Control Training* (*A-FACT*). A-FACT estimates BEA (degree towards, degree away) at each trial in real-time, and delivers personalized real-time feedback immediately following trial-level expressions of BEA (see Figure 1). A-FACT thus relies on an adaptation of the TL-BS computational procedure designed to estimate BEA, repeatedly, concurrent with the real-time expression of attention on each trial (Bernstein & Zvielli, 2014).[1] In the first test of A-FACT (Bernstein & Zvielli, 2014), we found that relative to a placebo control condition, A-FACT led to: (a) reduced aggregated mean levels of BEA to threat; (b) a (non-significantly) lower rate of behavioral avoidance of exposure to an anxiogenic stressor; and (c) a faster rate of emotional recovery following the stressor. In this first study of A-FACT, BEA modification was operationalized as change in the pre- to post-intervention aggregated mean levels of BEA (i.e., traditional "static" bias score). In light of findings reported by Zvielli, Bernstein, & Koster (2014a) on the nature, reliability and validity of the temporal dynamics of BEA, it is important that we next test whether A-FACT modifies BEA dynamics. Furthermore, in contrast to the initial development and test of "A-FACT 1.0" (Bernstein & Zvielli, 2014), the current "A-FACT 2.0" algorithm is closer to the TL-BS computation (Zvielli, Bernstein, & Koster, 2014a) (see Method Procedure below for details). We expected that this refined computation, and thus more precise feedback capacity, would lead to a more powerful effect on BEA dynamics and its behavioral consequents (e.g., anxious arousal in response to anxiogenic stressor).

Study Aims. Our primary aim was to test whether, relative to a placebo control, A-FACT modified BEA dynamics among high trait-anxious adults. Specifically, we expected that A-FACT would lead to significant improvement in key features of BEA dynamics (i.e., BEA towards threat parameters, BEA away from threat parameters, BEA temporal variability). Second, we tested whether, relative to placebo control, A-FACT would lead to reduced emotional reactivity (subjective state anxiety) in response to anxiogenic stress in the lab.

Method

Participants

Sixty-one high-anxious (State Trait Anxiety Inventory – Trait Anxiety (STAI) scores $\geq$ 39; (Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Massar, Mol, Kenemans, & Baas, 2011; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) young adult participants ($M(SD)_{age}$ = 23.8(3.3) years-old, $range_{age}$ 19-40; 76.3% female) were recruited from a university community in Israel. Twenty-nine were randomized to the A-FACT group and 32 to the placebo control condition. 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 BEA 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 diverse and representative sample relative to population norms in Israel (Israel Central Bureau of Statistics, 2011).

Measurement

Attentional Bias Measurement. The visual emotional dot probe task (MacLeod, Mathews, & Tata, 1986) was used to measure BEA 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, 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 (IT), the probe appeared in the location of the neutral stimulus, whereas on congruent trials (CT) the probe appeared in the location of the threat stimulus. Additional trials include two neutral stimuli (NT).

Procedure

I. *Pre-training Assessment.* Potential participants completed the trait anxiety section of the State-Trait- Anxiety Inventory (STAI; Spielberger et al., 1983). The identified sub-sample of high-anxious participants then attended a single laboratory session. Upon arrival to the laboratory, participants completed the State STAI, and 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, read participants a brief explanation that task instructions would be delivered via instructions on the computer monitor throughout the experiment. Participants then completed the visual emotional dot probe task (MacLeod et al., 1986; Mogg, McNamara, Powys, Rawlinson, Seiffer & Bradley, 2000) to measure pre-training levels of BEA to threat.

II. *Randomization to Condition.* Eligible participants were then randomized to either the (1) Attentional Feedback Awareness and Control Training (A-FACT) condition, or (2) 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 of the direction(s) (towards or away from threat) or the magnitude of their BEA.

A-FACT. 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 bias 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 (Figure 1). 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") related to the single immediately preceding trial only. Participants were instructed to try to learn from the feedback in order to reduce their BEA. 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 two training blocks (counter-balanced), 100 trials/block, composed of 20 ITs, 20 CTs, and 60 NTs, randomly distributed (no contingency) across each block, and thus up to 40 feedback trials were delivered per block. Two additional buffer NTs 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-minute break between training blocks. The rationale for providing feedback over two training blocks, with respect to two sets of stimuli, was to facilitate consolidation of learning even within the single A-FACT training session as well as to facilitate the generalizability of feedback-based learning about one's trial-level BEA beyond a specific set of visual stimuli. 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 BEA.

Personalized Feedback: Computation. RT on NT was used as an empirical reference to determine the degree to which each participant's RT on each specific CT or IT differed from their NT, and therefore BEA expressed on each individual CT/IT. To enhance the accuracy of trial-level BEA and thereby real-time feedback on trial-level BEA, in the current A-FACT 2.0 algorithm, the NT reference was updated using a "running mean" of NT RTs over the course of training; whereas in the earlier A-FACT 1.0 algorithm (Bernstein & Zvielli, 2014), the empirical reference was a fixed aggregated mean from pre-training NTs (Bernstein & Zvielli, 2014). NTs were used as the reference point for "no bias" because, by definition, BEA to threat stimuli cannot be observed on NTs; so doing provides a sensitive and personalized reference for non-biased RT per participant per trial.

As in Bernstein & Zvielli (2014), 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 some degree of BEA at pre-training. Furthermore, 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 towards threat *or* away from threat) as a function of her/his dominant BEA "direction" (towards or away) at pre-training. Thus, in the present single-session A-FACT experimental procedure, for example, if a participant expressed positive mean BEA scores (Mean IT-CT difference > +10ms) on 3 of 5 threat categories and mean negative BEA scores (Mean IT-CT difference < -10ms) in the two remaining categories, then she/he received feedback only for the three stimulus categories for which he showed bias *towards* threat. In so doing, we also guaranteed that feedback would be delivered with respect to as many personally-relevant stimulus categories as possible. This approach may be particularly important in light of recent findings suggesting that a person may express BEA towards one category of threat *and* away from another (Zvielli, Bernstein, & Koster, 2014b). As in A-FACT 1.0, feedback was not presented on error or RT-outlier trials.

Personalized Feedback: Presentation. Each feedback scale stimulus was presented for 3 sec, followed by 1.5 sec of a blank screen ITI preceding the next trial fixation cross. Following feedback, a random number of either 1 or 2 NTs were presented prior to the presentation of the next CT or IT to prevent predictability of feedback presentation and help ensure task engagement on subsequent CT/IT trials following a CT/IT feedback trial.

Active Placebo Control. 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, and the number of CT, IT and NT, and stimuli sets were identical to the A-FACT procedure. Thus, the active placebo condition was designed to control for each of the following alternative effects: 1) Pre-training knowledge of BEA and related expectancy effects was controlled for by instructing participants in both conditions that the computer found that their attention was biased to threat immediately following pre-training assessment of bias (i.e., “The computer has tested the way you allocate your attention, and found that your attention is affected by threatening stimuli.”). 2) Intervention (task) expectancy was controlled for by providing the same information to participants in both groups regarding the purpose of the training task: “The next task is designed to reduce your bias or the degree to which your attention is influenced by threat pictures”. 3) Repeated exposure to stimuli (desensitization or habituation) was controlled for by exposing both groups to the same sets and number of stimuli at baseline, training, and post-test.

III. ***Post-training emotional dot probe: Attentional bias re-test.*** Following the training phase, all participants again completed the emotional dot probe task, identical to the pre-training (pre-intervention) task. At re-test, all participants were instructed that their task was to again respond to the location of the probe as quickly and accurately as possible. 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 BEA were estimated at pre-training and for which feedback and placebo control was delivered.

IV. ***Anxiogenic threat exposure post-training: Emotional stress reactivity & recovery.*** Following the post-training measurement of attentional bias, participants were instructed to rate their levels of (current) state anxiety (SUA 0-100). Participants were then exposed to a randomized series of 5 threatening (negatively-valenced, high-arousal, fear-eliciting images) on a large full-screen display (i.e., one image per threat category for which BEA was tested; Bernstein & Zvielli, 2014; Erk et al., 2003; Pretz, Totz, & Kaufman, 2010). Each full-screen threatening image was followed by an emotionally-neutral stimulus. Each stimulus was displayed for a maximum duration of 15 sec. Participants were instructed that they were free to terminate the presentation of each image by pressing a key in the event that they feel unable to continue to view any specific image(s) (Leyro, Zvolensky, & Bernstein, 2010; Zvolensky, Leyro, Bernstein, & Vujanovic, 2011). Participants were then immediately shown a brief movie clip (200 sec) in which a person is trying to escape a villain in a dark, scary basement ("Silence of the Lambs", 1995; Rottenberg, Ray, & Gross, 2007). Participants were again instructed that they could terminate exposure to the film clip. Participants were instructed to rate their levels of (current) state anxiety following each threatening images and brief movie clip. Also, following termination of the anxiogenic stressor task, participants were instructed to rate their levels of (current) state anxiety (post-stressor SUA), and then to measure subjective emotional recovery, at 60 sec and then 120 sec following the scary movie. Finally, participants were debriefed and compensated via course credit or $20, per their choice.

Materials and Apparatus

Stimuli. Threat and neutral stimuli were a combined set from the International Affective Pictures System (Lang, Bradley, & Cuthbert, 1999) and additional images online (18 IAPS images, 12 images selected online; Bernstein & Zvielli, 2014), digitally resized to 8.5-cm width x 6.5-cm width-height (Bardeen & Orcutt, 2011; Bradley, Mogg, Wright, & Field, 2003; Mikels et al., 2005; Mogg et al., 2000). Distance between each pair of stimuli was 5.6-cm. Threat and neutral stimuli were validated in an independent sample in an earlier report (Bernstein & Zvielli, 2014).

Experimental set-up. Participants were seated such that their head was ~64 cm from the monitor. The experiment was run via E-Prime experimental presentation software (Schneider, Eschman, & Zuccolotto, 2002). The real-time TL-BS computations were conducted via E-prime run-time customized scripts. The experimental session was conducted on a Hewlett-Packard computer and 23" TFT monitor, in an acoustically-insulated room, with a one-way observation window and camera. Participants' responses were measured via Psychology Software Tools Serial Response Box™. Eye movements were also recorded but will be analyzed and reported in a separate manuscript. No other experimental tasks or experimental conditions were tested.

Trial-Level Bias Scores: Computation. To test group differences pre- to post-training levels of BEA between A-FACT and placebo conditions, we computed TL-BS by matching and then subtracting temporally contiguous pairs of Threat - Neutral (i.e., either CT or IT) trial's RT by subject. Each threat trial (CT or IT) was matched with the first next neutral trial (NT), to reduce any carry-over effects of other types of threatening stimuli. Matching of Threat-Neutral pairs was done to facilitate computation of TL-BS for each threat category independent of other types of threatening stimuli; importantly, this computation also paralleled the algorithm underlying A-FACT trial-level measurement of BEA and real-time feedback (see Method Procedure above).

Temporal Dynamics of Attentional Bias: Quantitative Parameters. To optimally estimate BEA as a dynamic process in time, we used the same 3 parameters (two of which are bi-dimensional) reported in Zvielli, Bernstein, & Koster (2014a): (1) **Mean TL-BS**. This parameter is bi-dimensional, and therefore calculated two-fold – (1a) **Mean TL-BS$_{\mathbf{POSITIVE}}$** - Individual differences in the degree to which mean TL-BS > 0ms or *towards* target stimuli; mean of TL-BSs > 0ms per participant; (1b) **Mean TL-BS$_{\mathbf{NEGATIVE}}$** - Individual differences in the degree to which TL-BS < 0ms or *away* from target stimuli; mean of TL-BSs < 0ms per participant. (2) **Peak TL-BS.** This parameter is also bi-dimensional, and therefore calculated two-fold – (2a) **Peak TL-BS$_{\mathbf{POSITIVE}}$** - Individual differences in the maximum phasic expression of trial-level BEA *towards* target stimuli; maximum TL-BS value per participant; (2b) **Peak TL-BS$_{\mathbf{NEGATIVE}}$** - Individual differences in the maximum phasic expression of trial-level BEA *away* from target stimuli; minimum TL-BS value per person. (3) **TL-BS Variability** reflects the degree of temporal stability or variability in the expression of BEA towards and/or away over time; sum of all distances between all sequential TL-BSs (i.e., length of TL-BS "line") divided by total number of TL-BSs. We tested the effects of A-FACT vs. placebo on each TL-BS parameter of BEA dynamics for the personalized threatening stimulus categories for which each participant received feedback in the A-FACT condition or would have received feedback in the control condition.

Data Analytic Plan: Bias Reduction. To test group differences in BEA we conducted Mixed Linear Model analyses (MLM) via the PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., 2008). Outcomes included TL-BS parameters – each in a separate model; fixed effects included trait anxiety (trait STAI levels), "Time" ("Pre-training", "Training Block 1", "Training Block 2", "Post-training" – discontinuously operationalized in the model), Group (A-FACT, Control) and the interaction of Time x Group interaction. The effect of Time was defined as a random effect – separately for each group – assuming a Toeplitz covariance matrix. Additionally, a random intercept was defined with a variance components covariance matrix. We used restricted maximum likelihood to estimate model parameters. To test the hypotheses, contrast analyses were applied with simulation-based multiple tests correction within each MLM to reduce alpha inflation (Edwards

& Berry, 1987). To test A-FACT effects on BEA dynamics (TL-BS parameters), the contrasts compared the change trajectory – from pre-training to the second feedback/placebo block (T1 to T3), and from pre-training to post-training (T1 to T4). Mean $TL\text{-}BS_{NEGATIVE}$ and Peak $TL\text{-}BS_{NEGATIVE}$ demonstrated positively-skewed distributions, and were thus logarithmically transformed before statistical analysis (Kronmal, 1993). Effect sizes of interaction effects were calculated (Hu, 2003).

Results

Pre-Training Anxiety. Levels of STAI trait anxiety were marginally greater in the control (N=32) than A-FACT condition (N=29) (*M*(*SD*) = 51.06(7.15); *M*(*SD*) = 47.06(5.43); $t_{(59)}$ = 2.44, p = .02; *d* = 0.64; respectively). In contrast, no differences between conditions were found in STAI state levels of anxiety at baseline (M(SD)=38.80(7.47); M(SD)=37.90(7.74), respectively; $t_{(59)}$ = .47, n.s, *d* = 0.12). We included trait anxiety as a covariate in all between-group analyses. Trait anxiety did not predict levels of BEA modification nor were any of the effects of A-FACT vs. placebo control, reported below, even marginally influenced by inclusion of trait anxiety levels as a covariate.

Data Preparation. In the pre-training, 2 training blocks, and post-training dot probe tasks, we discarded 1.1% error-response trials (i.e., "left" response when probe appeared on the right) and 1.7% RT outliers (trial RT <200 or >1500 ms, trial RT > or < 3 *SD*s of participant's mean RT) based on a priori criteria for valid trial selection.

Bias Modification. See Table 1 for levels of each TL-BS[2] parameter, by condition, at each time-point (pre-training, training blocks, post-training). First, prior to testing the effect of condition on each TL-BS parameter – within each MLM model – we tested whether there was a significant difference between groups on each TL-BS parameters at pre-training (i.e., to ensure successful randomization with respect to pre-training levels of each of the parameters of BEA dynamics). We found that for all five TL-BS parameters, there was no between-group difference at pre-training (β = -8.51 to 0.12, *SE* = -0.47 to 7.59, *DF* = 107.50 to 137.50, *t* =-1.75 to -0.11, *p* = .08 to .90).

Second, we tested expected group differences in change trajectories of BEA dynamics on each of the TL-BS parameters – from pre-training to the second training block, and from pre-training to post-intervention/placebo. The first two models examined change in BEA dynamics *towards* threat. A significant Time x Group interaction was found for Mean $TL\text{-}BS_{POSITIVE}$ ($F_{(3, 124)}$ = 3.52, *p* = .017, Ω^2=0.08); as predicted, in the change trajectory contrasts, A-FACT participants demonstrated significantly greater reduction in levels of Mean TL-$BS_{POSITIVE}$ than control group participants – from pre-training to the second training block (β = -22.67, *SE* = 7.60, $t_{(131)}$ = -2.98, *p* = .006), and from pre- to post-training (β = -19.60, *SE* = 7.62, $t_{(111.9)}$ = -2.57, *p* = .02). A significant Time x Group interaction was similarly found for Peak TL-$BS_{POSITIVE}$ (Group x Time: $F_{(3,\ 133)}$ = 4.77, *p* = .003, Ω^2=0.06); again, as predicted, A-FACT participants demonstrated significantly greater reduction in levels of Peak TL-$BS_{POSITIVE}$ than control group participants – from pre-training to the second training block (β= -0.39, *SE* = 0.11, $t_{(135.5)}$ = -3.44, *p* = .001), and from pre- to post-training (β = -.36, *SE* = 0.12, $t_{(135.8)}$ = -2.97, *p* = .007).

Third, we tested the effects of condition on *variability* in BEA. A significant Time x Group interaction was found for TL-BS Variability ($F_{(3,\ 176)}$ = 3.69, *p* = .013, Ω^2=0.07); as predicted, A-FACT participants demonstrated significantly reduced levels of TL-BS Variability than control group participants – from pre-training to the second training block (β = -0.26, *SE*=0.08, $t_{(175.8)}$ = -3.07, *p* = .0045), and from pre- to post-training (β = -0.22, *SE* = 0.09, $t_{(175.8)}$ = -2.53, *p* = .022).

Finally, we tested the expected group differences on change trajectories reflecting BEA dynamics *away* from threat. Inconsistent with prediction, for both Mean TL-$BS_{NEGATIVE}$ and Peak TL-$BS_{NEGATIVE}$, the Time x Group interactions were non-significant ($F_{(3,\ 176)}$ < 1, *n.s*. Ω^2=0.01; $F_{(3,\ 123)}$ < 1, *n.s*, Ω^2=0.00; respectively); change trajectories by condition were not tested in light of the null interactions. One possible explanation for these null effects is that there was insufficient BEA *away* from threat to observe modification on these features of BEA dynamics *away* from threat; however, descriptive data on BEA *towards* and *away* from threat directly challenge this explanation (see Table 1). Thus, post-hoc, we tested whether only participants who received feedback for BEA *away* from threat were able to gain awareness and act to control BEA *away* from threat (cf. participants who received feedback for BEA *towards* threat). Thus, to explore this post-hoc hypothesis, we tested the effect of A-FACT (N=11) vs. placebo control (N=18) in the sub-sample of participants who received feedback for BEA *away* from threat. The Time x Group interaction for Mean TL-$BS_{NEGATIVE}$ [log transformed] neared significance ($F_{(3,\ 81)}$ = 2.16, *p* = .099, Ω^2=0.01). In light of the post-hoc nature of the analysis, and small sample size that limited the statistical power of detecting an interaction, we nevertheless tested the change trajectories by condition. As intuited post-hoc, we found that levels of Mean TL-$BS_{NEGATIVE}$ were significantly improved (less BEA *away* from threat) in A-FACT but not control participants – from pre-training to the second training block (β -.33, *SE* = 0.16, $t_{(81)}$ = -2.14, *p* = .035), and from pre- to post-training (β = -.33, *SE* = 0.16, $t_{(81)}$ = -2.14, *p* = .035). In addition, the Time x Group interaction for Peak TL-$BS_{NEGATIVE}$ [log transformed] was not significant ($F_{(3, 36.6)}$ <1, *n.s,* Ω^2=0.00). Again, in light of the post-hoc nature of the analysis, and small sample size that limited the statistical power of detecting an interaction, we nevertheless tested the change trajectories by condition. However, unlike for Mean TL-$BS_{NEGATIVE}$, we found that levels Peak TL-$BS_{NEGATIVE}$ [log transformed] did not significantly improve relative to placebo from pre-training to the second training block (β = -.18, *SE* = 0.19, $t_{(39.4)}$ = -0.96, *p* = .34), nor from pre- to post-training (β = -0.27, *SE* = 0.18, $t_{(42.6)}$ = -1.47, *p* = .15).

Emotional Reactivity and Recovery to Anxiogenic Stressor. See Figure 2 for subjective anxiety levels at pre- and post training, and then over 9 time-points following training – from pre-stressor through to post-stressor recovery. To test the effect of condition on subjective emotional reactivity to the anxiogenic stressor a MLM model was fitted. Seven time-points (pre-stressor, post-pictures 1 to 5, post-movie) were treated continuously, assuming a single trajectory of subjective anxiety per group from pre- to post-stressor. The model tested the difference between group slopes using Group X Time interaction term, applying similar random effects specifications as in the previous analysis. Finally, we tested if each of the slopes differed from zero within the same statistical framework. Consistent with successful randomization, no difference in subjective anxiety was detected pre-stressor between control and A-FACT groups (β = -2.68, *SE* = 6.06, $t_{(125.4)}$ = -0.44, *p* = 1.00). As hypothesized, placebo control participants demonstrated significantly greater elevations in anxiety from pre- to post-stressor than A-FACT participants ($F_{(1,94)}$=5.23, *p* = 0.02, Ω^2=0.08). Specifically, whereas participants in the control condition showed significant elevation in subjective anxiety from pre- to post-stressor (β = 2.77, *SE* =.68, $t_{(46)}$ = 4.08, *p* < .001), participants who received A-FACT did not similarly show evidence of emotional reactivity in response to the stressor (β = 0.96, *SE* =.61, $t_{(52)}$ = 1.58, *p* = .12). In light of these large differences in reactivity by condition, we were not able to test differences in recovery post-stressor. In contrast to control group participants, participants in the A-FACT condition maintained low levels of subjective anxiety at post-stressor similar to their pre-stressor levels, such that there was no emotional *recovery* following the stressor to quantify (see Figure 2).

Discussion

First, we found that relative to the placebo control condition, A-FACT led to significantly reduced BEA dynamics towards threat stimuli (i.e., Mean $\text{TL-BS}_{\text{POSITIVE}}$ and Peak $\text{TL-BS}_{\text{POSITIVE}}$ parameters) as well as to significantly reduced temporal variability in BEA (i.e., TL-BS Variability parameter); inconsistent with prediction, we did not find an overall group effect on BEA dynamics away from threat stimuli (i.e., Mean $\text{TL-BS}_{\text{NEGATIVE}}$ and Peak $\text{TL-BS}_{\text{NEGATIVE}}$ parameters). In a post-hoc test, we found that relative to placebo control participants, participants that received A-FACT for BEA *away* from threat demonstrated significantly reduced BEA *away* from threat stimuli on one TL-BS parameter (i.e., Mean $\text{TL-BS}_{\text{NEGATIVE}}$) but not on a second TL-BS parameter (i.e., Peak $\text{TL-BS}_{\text{NEGATIVE}}$).[3] Second, we found that A-FACT was protective against anxiogenic stress – placebo control participants demonstrated significantly greater anxious reactivity to the stressor than participants who received A-FACT (see Figure 2). These findings are consistent with the idea that meta-awareness and thereby self-regulatory control of (biased) attention, trained through real-time feedback, may help short-circuit “downstream” processes driven by typically unmonitored and uncontrolled BEA, such as emotional reactivity to anxiogenic stress (Bernstein & Zvielli, 2014).

The observed findings are important in so far as they may help guide the development and delivery of the clinical modification of BEA, as well as deepen our understanding of BEA. First, the present study tested whether BEA dynamics may be targeted by means of real-time feedback (Bernstein & Zvielli, 2014). This represents the first effort to examine the effect of A-FACT, or any form of CBM, on the therapeutic modification of BEA dynamics. In so far as BEA dynamics are important to psychopathology etiology and maintenance, effectively targeting these key features of BEA may ultimately prove clinically important. Second, the present findings suggest that intervention methods sensitive to and capable of targeting *BEA process dynamics in real-time* – as illustrated by A-FACT – represent a promising new direction for CBM. Such progress may be important in light of the modest and mixed findings of ABMT to-date (e.g., Mogoaşe et al., 2014; Hallion & Ruscio, 2011). Third, the present study findings may also help guide the *personalized delivery* of A-FACT, and other emerging CBM interventions, to optimally target BEA dynamics. Specifically, in the present study and delivery of A-FACT, each participant received real-time feedback targeting *either* BEA towards *or* BEA away from threat, but not both. Conceptually, we speculated that gaining meta-awareness and thereby control over BEA *towards* threat through real-time feedback could translate directly into meta-awareness and a similar capacity to control BEA *away* from threat stimuli. The observed findings, however, were not consistent with this idea. Rather, at least in the context of this brief, single-session A-FACT format among trait anxious adults, findings suggest that real-time feedback should target BEA towards *and* away from threat stimuli. This may be done by either providing feedback with respect to BEA towards *and* away in separate training blocks; or in blocks wherein "combined feedback" for BEA towards *and* away from threat is delivered, per trial, as a function of each participant's real-time expression of BEA towards *or* away from motivationally-relevant stimuli in time per trial.

The present findings also deepen our understanding of BEA and inform new directions for basic research. First, the present findings were consistent with those reported by Zvielli, Bernstein, & Koster (2014a) in spider phobics and deprived smokers. Indeed, we found that BEA to threat in trait-anxious participants was dynamic, characterized by temporal variability in differential attending towards *and* away from threat in time. In addition to replicating and extending earlier findings of BEA dynamics, the present study and findings illustrate that quantifying BEA as a process, through the TL-BS computational approach, more faithfully reflects the complexity of the phenomenon. Studying the phenomenon in a manner that most closely reflects its complexity is key to advancing basic science knowledge of BEA. So doing may, for example, enable research that transcends levels of analysis to illuminate neurocognitive mechanisms underlying BEA expression (e.g., identification of neural generators of BEA dynamics). Second, the present findings are in line with theorizing that training a person to monitor and gain meta-awareness of her well-rehearsed, often automatic, and typically unmonitored dynamic expression of BEA in time – and its component attentional processes – may enable self-regulatory attentional control and thereby remedy BEA dynamics. These findings thus also illustrate the need to develop methodology to directly measure meta-awareness of BEA concurrent with its real-time expression in the laboratory. We believe that ultimately, such measurement methods will be important to illuminate the theorized mechanism of A-FACT, and more broadly, to understand the role of meta-awareness of BEA on BEA expression and on the relations between BEA dynamics and (mal)adaptive psycho-behavioral processes (e.g., approach-avoidance behavior, emotion). Finally, the field may benefit from re-analysis of published and unpublished ABM intervention studies by quantifying BEA, and therapeutic change in BEA, as a dynamic process (rather than as a static trait via aggregated mean bias scores). Such re-analyses may change our understanding of the effects of conventional ABMT on BEA.

The present study has a number of limitations important to guiding next steps in this line of study. First, participants were trait anxious adults recruited from a university community. It is important that future study attempt to deliver A-FACT to a clinical sample in an effort to modify the temporal dynamics of BEA and test its effects on clinical psycho-behavioral processes linked to BEA. 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 important next steps in this line of study. Third, we did not directly measure meta-awareness of BEA. Development of a measurement methodology to do so may be an important step in elucidating the theorized mechanism through which A-FACT may affect BEA and related outcomes. Fourth, the control condition was designed to rule-out that group differences may be alternatively explained by training knowledge of BEA and related expectancy effects, intervention expectancy, and repeated exposure to stimuli (desensitization or habituation). Indeed, the placebo control was sufficiently effective to reduce BEA significantly from pre-training to the first training block. Future research may also compare A-FACT to sham feedback and other alternative, active conditions. Fifth, anxious responding to the anxiogenic stressor was limited to self-report. Future work may look at psychophysiological and behavioral indices of anxiety-related processes beyond subjective anxiety. Finally, though no differences were observed between groups in state anxiety, we observed a small between-group difference in trait anxiety prior to training. However, MLM analyses demonstrated that levels of trait anxiety were not related to change in BEA from pre- to post-training (i.e., BEA modification outcomes), nor did the inclusion of trait anxiety levels as a covariate (even marginally) affect the reported effects of A-FACT, relative to placebo control, on BEA modification or anxiogenic stress responding outcomes.

In summary, we hope this study contributes to the field-wide goal of better understanding and effectively targeting BEA as a means to short-circuit psychopathology and promote mental health. Furthermore, we speculate that study of BEA as a dynamic process and its clinical modification through real-time feedback provides a useful framework for study of other psychological processes. Indeed, there are a number of psychological processes that may be dynamic, but have been studied as static traits through the same "aggregated mean" paradigm underlying cognitive-experimental tasks used to study BEA (e.g., motivated and implicit cognition, approach-avoidance behavior, awareness, etc.). In so far as such psychological processes are well-rehearsed, often automatic, typically unmonitored, and have implications for human performance or (mal)adaptation, real-time feedback may be adapted to target these dynamic psychological processes as well.

Table 1. Means and Standard Deviations for TL-BS Parameters by Group

		Pre-Test	**Training Block I**	**Training Block II**	**Post-Test**
			M (SD)		
Mean TL-BS$_{POSITIVE}$	A-FACT (N=29)	73.62 (36.02)	58.49 (23.52)	55.18 (25.32)	62.06 (25.16)
	Control (N=32)	65.34 (21.59)	67.40 (28.51)	69.56 (35.99)	73.33 (28.18)
Mean TL-BS$_{NEGATIVE}$	A-FACT (N=29)	-69.41 (22.57)	-63.94 (29.62)	-57.54 (31.85)	-65.93 (36.73)
	Control (N=32)	-66.49 (19.86)	-66.52 (27.24)	-63.16 (25.05)	-71.27 (30.66)
Peak TL-BS$_{POSITIVE}$	A-FACT (N=29)	189.11 (107.13)	114.70 (64.26)	101.11 (49.16)	160.11 (97.80)
	Control (N=32)	151.30 (56.77)	130.37 (61.34)	126.42 (60.64)	188.28 (94.23)
Peak TL-BS$_{NEGATIVE}$	A-FACT (N=29)	-165.43 (67.87)	-111.87 (55.12)	-111.69 (68.65)	-167.49 (99.51)
	Control (N=32)	-161.90 (58.91)	-130.67 (61.89)	-115.59 (53.43)	-184.69 (87.92)
TL-BS Variability	A-FACT (N=29)	101.47 (36.90)	79.79 (36.84)	71.88 (30.33)	88.99 (39.77)
	Control (N=32)	92.19 (28.55)	86.91 (33.28)	85.66 (36.09)	100.49 (36.07)
***Mean TL-BS$_{NEGATIVE}$**	A-FACT (N=11)	-74.57 (23.37)	-56.86 (29.71)	-53.59 (25.88)	-57.33 (20.67)
	Control (N=18)	-69.09 (21.19)	-66.30 (24.67)	-66.89 (26.22)	-74.65 (27.21)
***Peak TL-BS$_{NEGATIVE}$**	A-FACT (N=11)	-169.73 (67.54)	-101.64 (64.91)	-102.86 (56.05)	-152.73 (68.88)
	Control (N=18)	-173.75 (68.45)	-127.26 (45.24)	-117.72 (43.47)	-201.41 (92.84)

Note. * Effects on BEA dynamics *away* from threat among participants who received feedback for BEA *away* from threat specifically.

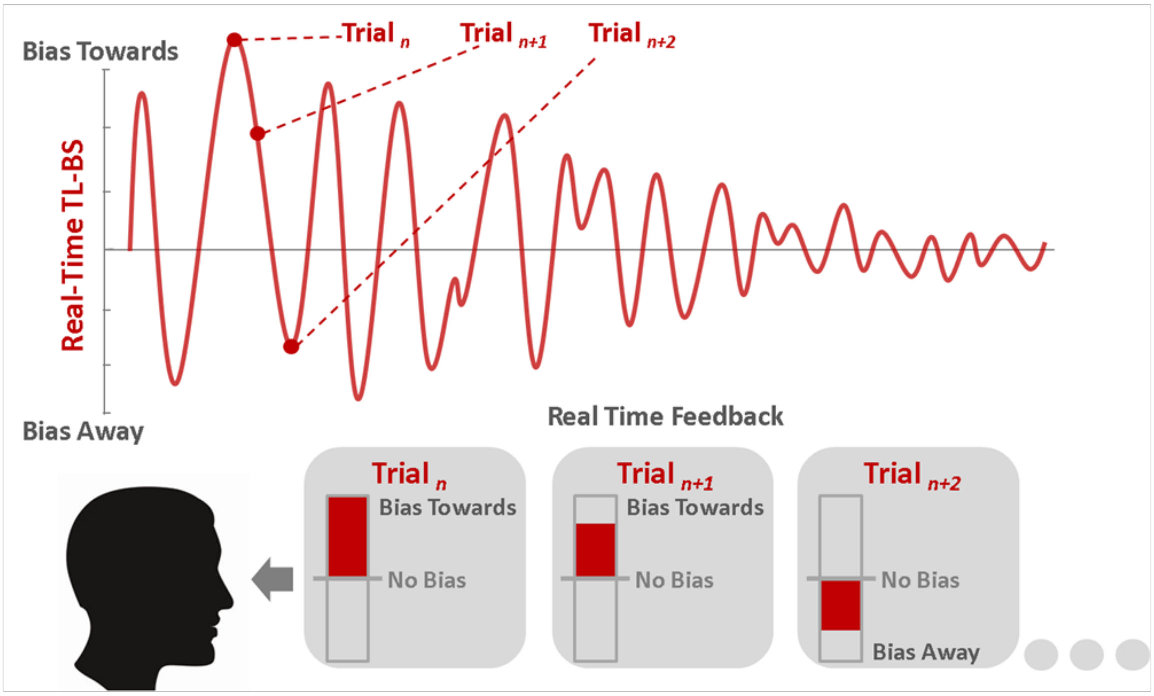

Figure 1. Illustration of Real-Time Feedback on Attentional Bias (A-FACT) Based on Real-Time Trial-Level Bias-Score Methodology.

Note. Real-time feedback is presented immediately following each trial-level bias expression: i.e., **Trial$_n$** Emotional stimulus ► Response (RT) ► Real-Time TL-BS Computation ► Real-Time Feedback Delivery…**Trial$_{n+1}$** Emotional stimulus ► Response (RT) ► Real-Time TL-BS Computation ► Real-Time Feedback Delivery…**Trial$_{n+2}$**… **Trial$_{n+3}$**…

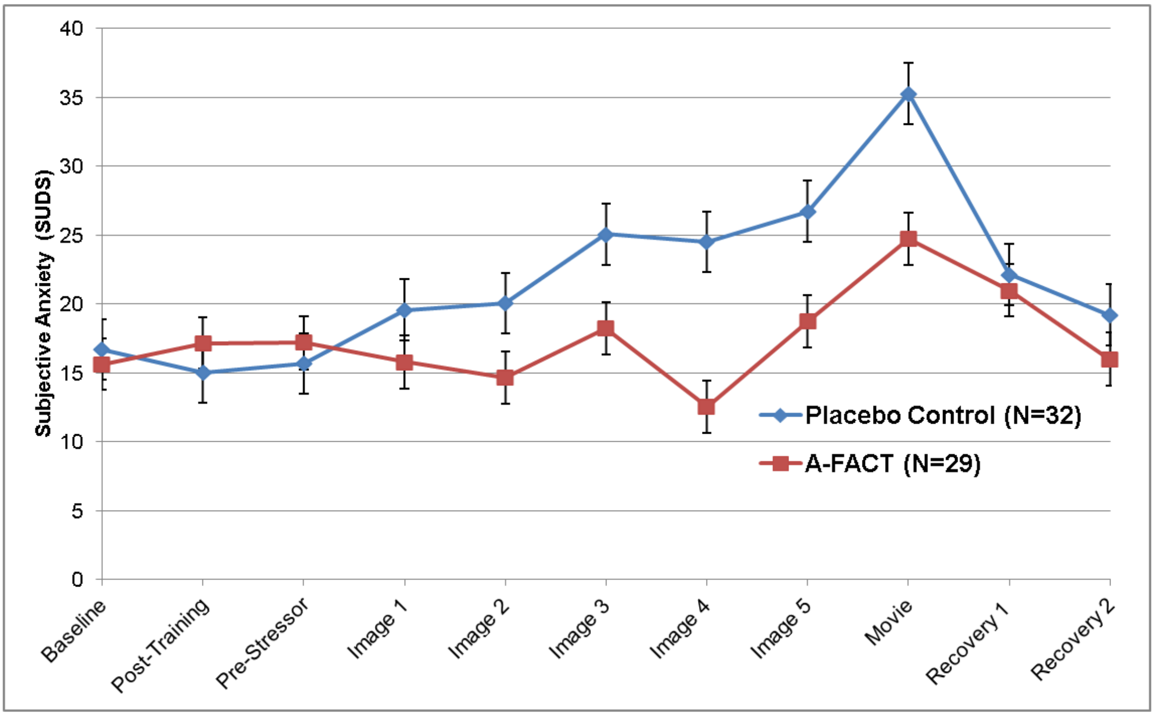

Figure 2. Subjective Anxiety Ratings by Group.

Footnotes

1. In theory, a number of methods may be adopted to capture and modify BEA temporal dynamics. We selected real-time feedback as the initial intervention modality for a number of reasons. First, real-time feedback is designed to deliver a series of trial-level "mini-interventions" as a function of the dynamic expression of BEA from moment-to-moment. This approach is in contrast to conventional ABMT modification methodology that delivers training that is not contingent – not sensitive to, nor a function of – the dynamic expression of BEA (cf. training participant to disengage from threat stimuli at a given moment in time regardless of their attentional expression at that moment). Second, real-time feedback is designed to facilitate meta-awareness of and thereby enable self-regulatory control of (biased) attention and behavior driven by typically unmonitored dynamic expression of BEA from moment-to-moment (i.e., trial-to-trial) in real-time (see Bernstein & Zvielli, 2014 for details).

2. Trial-Level Bias-Scores Descriptive Statistics. At pre- and post-training, out of 40 ITs, 40 CTs and 80 NTs per stage, the maximum possible TL-BS calculations per person, per category, was 16 (80/5), but could be lower due to error responses or outlier RT. Accordingly, the number of computed TL-BS estimations per participant, per category, per stage (pre- and post-training) was $M(SD)$ = 15.41(0.40), Range = 13.8 to 16.0. In the feedback/placebo intervention blocks, out of 20 ITs, 20 CTs and 60 NTs, the maximum possible TL-BS calculations per person, per category, was 8 (i.e., 40/5). Accordingly, in feedback/placebo intervention blocks, out of 20 ITs, 20 CTs and 60 NTs, the number of computed TL-BSs per block was $M(SD)$ = 7.73(0.41), Range = 6.4 to 8.

3. There may be a number of accounts for these mixed findings, such as, the limited statistical power of this post-hoc analysis in the sub-sample of N=11 (A-FACT) and N=18 (control) participants.

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