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Mental Health on the Go: Effects of a Gamified Attention-Bias Modification Mobile Application in Trait-Anxious Adults

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Abstract
Interest in the use of mobile technology to deliver mental-health services has grown in light of the economic and practical barriers to treatment. Yet research on alternative delivery strategies that are more affordable, accessible, and engaging is in its infancy. Attention-bias modification training (ABMT) has the potential to reduce treatment barriers as a mobile intervention for stress and anxiety, but the degree to which ABMT can be embedded in a mobile gaming format and its potential for transfer of benefits is unknown. In the present study, we examined effects of a gamified ABMT mobile application in highly trait-anxious participants (N = 78). A single session of the active training relative to the placebo training reduced subjective anxiety and observed stress reactivity. Critically, the long (45 min) but not the short (25 min) active training condition reduced the core cognitive process implicated in ABMT (threat bias) as measured by an untrained, gold-standard protocol.

Keywords
attention-bias-modification training, mobile application, anxiety, stress, gamification

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Only a small fraction of people suffering from mental-health problems is able to seek and receive treatment. For example, anxiety disorders are the most common of the psychiatric disorders and affect 29% of individuals during their lifetime (Kessler et al., 2005; Kessler, Petukhova, Sampson, Zaslavsky, & Wittchen, 2012). Of the approximately 90 million individuals this represents in the United States alone, as many as 50% do not seek or receive treatment. This result is largely due to both practical barriers to treatment (cost and accessibility) and problems with the acceptability of treatment options (high cost, stigma, and large time commitment; Greenberg et al., 1999; Kessler et al., 2008; Kessler & Wang, 2008). With recent advances in the development and refinement of effective, evidence-based treatments (Kazdin & Blase, 2011; Kazdin & Rabbitt, 2013), the discrepancy between mental-health needs and access to services is all the more concerning.

This crisis in the mental-health field has sparked a dialogue in psychology and other health-related fields about the need to develop alternative strategies for delivery of services (Christensen, Miller, & Muñoz, 1978; Harwood & L'Abate, 2010; Kazdin & Blase, 2011; Kazdin & Rabbitt, 2013; L'Abate, 2007; Mosa, Yoo, & Sheets, 2012; Rotheram-Borus, Swendeman, & Chorpita, 2012; Ryder, 1988). Particular attention has been paid to computerized and mobile interventions, given their potential to serve as "disruptive innovations" that provide a qualitative leap in reducing costs of and increasing accessibility to empirically validated treatments (e.g., Barak, Hen, Boniel-Nissim, & Shapira, 2008; Kazdin & Rabbitt, 2013; Rotheram-Borus et al., 2012). Moreover, the ubiquity of mobile devices provides a unique opportunity to broaden the reach of psychological services to many individuals who might not otherwise have access (Dimeff, Paves, Skutch, & Woodcock, 2011; Kazdin & Rabbitt, 2013; Morris et al., 2010). Of the 91% of American adults who

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own cell phones, fully half of them, a number approaching 150,000,000, use mobile applications, or apps, on their phones, and 60% use their handheld device to access the Internet (Duggan, 2013).

The games for health movement (Buday, Baranowski, & Thompson, 2012; Ferguson, 2012; Kato, 2012; Rahmani & Boren, 2012) takes this idea further by exploring ways in which effective interventions can be translated into game format (e.g., gamelike interfaces, points and rewards, animated graphics) to reduce problems with treatment engagement and compliance and to increase use of prevention technologies. Although recent, widely publicized research has demonstrated that a video game successfully enhanced cognitive control in older adults (Anguera et al., 2013), this research is the exception. Thus, the promise of mobile technology for the delivery of mental-health services remains vastly underexplored and understudied, and it is largely unknown whether treatment approaches embedded in a game format—or gamification—result in transfer of benefits to gold-standard, lab-based assessments (e.g., Buday et al., 2012; Rahmani & Boren, 2012).

Attention-bias-modification training (ABMT) is an emerging computer-based therapeutic approach rooted in neurocognitive models of anxiety that overcomes many obstacles to treatment. It has been discussed as having significant potential both as an enhancement to state-of-the art psychological and pharmacological treatments for anxiety and as a stand-alone treatment (Bar-Haim, 2010; Hakamata et al., 2010). Thus, ABMT is a prime candidate for development into mobile, gamified interventions, but it is unknown whether ABMT effects will be retained in a gamified format. This is the goal of the present study.

ABMT emerged from research on core attention disruptions that play a role in the etiology and maintenance of anxious pathology (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Brotman et al., 2007; Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Mathews & Mackintosh, 1998; Mathews & MacLeod, 1985, 2002). In particular, exaggerated attention to threat, termed the *threat bias*, has been examined as a causal mechanism in anxiety (Hakamata et al., 2010; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; Mohlman, 2004; Puliafico & Kendall, 2006). The threat bias, which is thought to emerge in childhood (Puliafico & Kendall, 2006; Roy et al., 2008), is implicated in the emergence and expression of anxiety across diagnostic categories (Bar-Haim et al., 2007) and predicts a persistent course of anxiety from childhood to adulthood (Bar-Haim et al., 2007; Pérez-Edgar et al., 2010; Pérez-Edgar et al., 2011). A meta-analysis (Bar-Haim et al., 2007) confirmed the presence of threat bias in both pediatric and adult anxiety and showed that this bias was robust across anxiety disorders but was not present in nonanxious participants. This selective and exaggerated attention to threat may contribute to the continuity of anxiety by facilitating preferential processing of threat at the expense of pleasant cues or cues for safety. This, in turn, may spark a vicious cycle in which anxiety is heightened, attention to threat is further facilitated, and opportunities for disconfirmation of fear beliefs are minimized (e.g., Hofmann, 2007).

In ABMT, attention is trained away from threat by creating attentional competition between a threat and a nonthreat stimulus and repeatedly directing participants' attention toward the nonthreat stimulus. A recent meta-analysis of ABMT using this simple technique showed that ABMT not only resulted in reduced threat bias with a large effect size (d = 1.16) but also produced significantly greater reductions in anxiety than did placebo training (PT) with a medium effect size (d = 0.61); these effects were consistently sustained at follow-ups varying between 1 and 6 months (Hakamata et al., 2010). In addition to reductions in state anxiety for highly trait-anxious participants (Eldar & Bar-Haim, 2010), several studies have shown that ABMT results in reduced symptoms of several anxiety disorders, including generalized anxiety disorder (Amir, Beard, Burns, & Bomyea, 2009), social phobia (Amir, Beard, Taylor, et al., 2009), pathological worry (Hazen, Vasey, & Schmidt, 2009), and social anxiety disorder (Klumpp & Amir, 2010), comparable with the effect size of a typical 12-session cognitive-behavioral-therapy intervention after 1 month (Hakamata et al., 2010). Stress reactivity is also reduced by ABMT. For example, a study with highly trait-anxious youth showed that participants assigned to an ABMT versus a control training condition showed less stress-induced anxiety after a task-based stressor (Bar-Haim, Morag, & Glickman, 2011).

Given this evidence base that ABMT has the potential to effectively reduce threat bias, anxiety symptoms, and anxiety-related stress reactivity, combined with the fact that ABMT overcomes many treatment barriers by being brief and inexpensive, ABMT is a prime candidate for mobile-based intervention approaches. Drawing on this evidence, in several studies, researchers have modified ABMT for use on mobile devices or to be delivered via the Internet (Amir & Taylor, 2012; Boettcher et al., 2013; Carlbring et al., 2012; Enock & McNally, 2013; MacLeod, Soong, Rutherford, & Campbell, 2007). However, these studies resulted in inconsistent results and, crucially, did not address the need to increase individual engagement and acceptability of interventions (Buday et al., 2012; Ferguson, 2012; Kato, 2012; Rahmani & Boren, 2012). For youth and young adults in particular, gamifying interventions can make them more appealing, reduce stigma, and increase compliance. Moreover, given the effects of ABMT on stress reduction, the wider use of ABMT to reduce stress and stress-related disorders would be greatly facilitated by the development of enjoyable, gamified interventions that are mobile and, thus, readily accessible and affordable.

Our goal in the present study was to examine effects of a gamified ABMT mobile application in a sample of highly trait-anxious participants. To do so, we took the core components of the gold-standard ABMT protocol (the dot-probe task; MacLeod, Mathews, & Tata, 1986) and designed an appealing game around the basic task parameters while incorporating video game–like features, such as animated characters, points, and sound effects. We administered a short training condition of the app (25 min with 20 min of rest) and a long training condition of the app (45 min with no rest) on the basis of commonly used numbers of trials for ABMT tasks (Eldar & Bar-Haim, 2010; Eldar et al., 2012) as an initial exploration of "dosage effects." We examined whether this gamified ABMT app affected the threat bias, anxiety, and stress reactivity of trait-anxious individuals in ways similar to traditional, lab-based ABMT by testing three hypotheses. First, we tested the prediction that threat bias measured via an independent computerized task would be reduced among participants in the ABMT versus the PT version of the app. Second, we tested the prediction that subjective anxiety and observed anxious stress reactivity would be reduced among participants in the ABMT versus the PT version of the app. Finally, because threat bias is the hypothesized target of ABMT, we explored whether reductions in the independent measure of threat bias predicted reduced subjective anxiety and stress reactivity and whether this varied between the short and long training conditions.

Method

Participants

Participants were adults recruited from an Introduction to Psychology course at an urban university in New York City. The long training condition included 38 participants (27 females, 11 males; mean age = 22.34, *SD* = 6.91, range = 17–50) who were randomly assigned to either an ABMT or a PT condition (19 per group). The short training condition was conducted after the long training condition was completed. It included 40 participants (28 females, 12 males; mean age = 20.23, *SD* = 4.08, range = 17–38) who were randomly assigned to either an ABMT or a PT condition (20 per group). However, 2 of these participants were excluded from analyses because they did not complete the app, which left 18 participants in the short ABMT group and 20 in the short PT group. Demographic characteristics for each of the four groups are reported in Table 1.

Procedure

The procedure was identical for both the long and the short training conditions. Participants were recruited if they scored 1 standard deviation above the mean for college students on trait anxiety (a score of 49) using the State-Trait Anxiety Inventory (STAI; Spielberger, 1983).

Table 1. Participant Demographics, Trait Anxiety, and Depression Symptoms

	Training condition			
	Short		Long	
Characteristic/measure	ABMT (*n* = 18)	PT (*n* = 20)	ABMT (*n* = 19)	PT (*n* = 19)
Gender (% women)	60	80	78.90	63.20
Age (years)	20.65 (5.11)	19.8 (2.78)	22.79 (7.87)	21.89 (5.99)
Education (years)	14.55 (2.05)	15.18 (3.71)	15.59 (3.89)	14.42 (1.54)
Ethnicity (*n*)				
Hispanic/Latino	5	6	0	2
American Indian	0	1	0	0
Asian	4	6	9	5
Native Hawaiian or Other Pacific Islander	1	0	0	1
Black	1	2	0	1
White	3	5	10	7
More than one race	4	0	0	3
Trait anxiety	48.44 (7.85)	51.25 (9.91)	53.12 (7.75)	51.74 (7.83)
Depression symptom	15.65 (9.32)	15.20 (10.20)	19.95 (11.55)	16.74 (7.97)

Note: Unless noted otherwise, the table presents means, with standard deviations shown in parentheses, for each characteristic/measure. ABMT = attention-bias-modification training; PT = placebo training.

Participants spent approximately 2 hr in the laboratory. After a brief questionnaire period, during which participants answered demographic questions and provided self-reports of state anxiety and depressed mood, we asked participants to complete the pretraining threat-bias assessment using the dot-probe task; the stimuli were presented at a viewing distance of 65 cm from the participant on a 17-in monitor. Next, participants sat comfortably at a table in a separate room and completed the ABMT or the PT on an iPod Touch (fourth generation). After the training session, participants immediately reported on their state anxiety and completed the posttraining threat-bias assessment using the dot-probe task. Finally, participants reported on positive and negative mood using the Profile of Mood States questionnaire (POMS; McNair, Lorr, Heuchert, & Droppleman, 2003), completed the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993), and again reported on positive and negative mood using the POMS.

Measures

Baseline mood questionnaires. Baseline trait anxiety and depression symptoms for each of the four groups of participants are reported in Table 1. The trait-anxiety score was derived from the STAI; scores range from 20 to 80, and higher scores indicate greater anxiety (Spielberger, 1983). Depression symptoms were measured using the Beck Depression Inventory II (Beck, Steer, & Brown, 1996); scores range from 0 to 63 (0–13 = minimal; 14–19 = mild; 20–28 = moderate; 29–63 = severe).

The dot-probe task and stimuli. The dot-probe task is the most commonly used computerized task for measuring threat bias and best reflects naturalistic conditions in that threatening and nonthreatening stimuli compete for attention, rather than presenting threatening stimuli alone (Bar-Haim et al., 2007; Mathews & Mackintosh, 1998). The dot-probe protocol followed parameters consistent with the Tel Aviv University/National Institute of Mental Health protocol (http://www.tau.ac.il/~yair1/ABMT.html). Stimuli for the dot-probe task were pictures of 20 individuals (10 males, 10 females) from the Nim-Stim set (Tottenham et al., 2009), with 1 female taken from the Matsumoto and Ekman (1989) set. Stimuli were programmed using E-Prime version 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

During each trial of the task, two pictures were presented—either angry-neutral face pairs or neutral-neutral face 55-mm x 55-mm, pairs (depicted by the same individual). The pictures were shown above and below a fixation cross with a 14-mm space between them. The task included 120 trials (80 angry-neutral and 40 neutral-neutral face pairs). Each trial was composed of (a) a 500-ms fixation, (b) a 500-ms face-pair cue, (c) a target (probe) in the location of one of the faces and visible until a response was made via the left or right mouse button to indicate the direction in which the arrow was pointing, and (d) a 500-ms intertrial interval (see Fig. 1 for an example stimulus display). Participants were asked to indicate, as quickly and as accurately as possible, whether the arrow was pointing to the left or to the right. Probes were equally likely to appear on the top or the bottom, in the location of the angry- or the neutral-face cues, and pointing to the left or to the right.

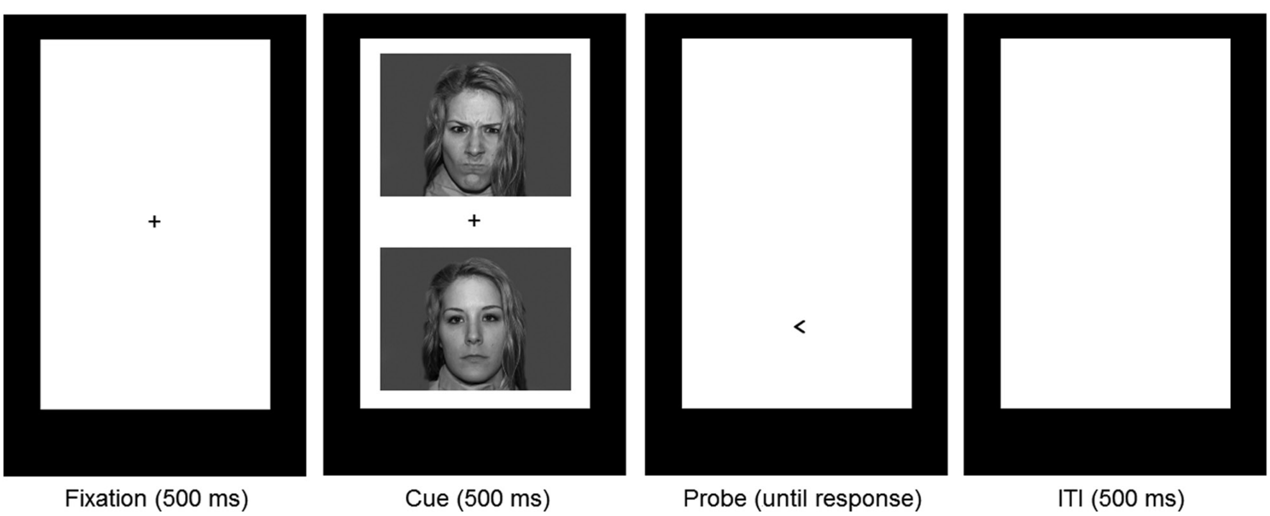

Fig. 1. Example stimulus display from the dot-probe task. Participants' task was to indicate whether the arrow (probe) was pointing to the left or to the right. ITI = intertrial interval.

Reaction times (RTs) were filtered by removing responses that were faster than 3 standard deviations below an individual's mean and slower than 3 standard deviations above an individual's mean. Using only correct trials from the dot-probe task, we obtained three threat-bias scores (attentional bias, vigilance, and disengagement) by comparing RTs for the different probe conditions. In the angry-face probe condition, the target replaces the angry face from a pair of angry and neutral faces, whereas in the neutral-face probe condition, the target replaces the neutral face from a pair of angry and neutral faces. In the baseline probe condition, the target replaces either face from a pair of neutral faces.

The attentional-bias score is calculated as the average RTs for neutral probes–angry probes. Higher scores indicate an attentional bias toward threatening information, such that participants respond faster when the probe appears in the location of the angry face versus the neutral face (i.e., under conditions in which threat competes for attention with nonthreat). This bias can be driven by the speed of attentional capture by threat (vigilance) or the length of attentional hold by threat (disengagement). The vigilance score is calculated as the average RTs for baseline probes–angry probes. Higher scores indicate greater attentional capture by threat, such that participants respond faster when the probe appears in the location of the angry face versus when no threatening face is presented. The disengagement score is calculated as the average RTs for neutral probes–baseline probes. Higher scores indicate greater attentional hold by threat, such that participants are faster to respond when no threat is presented versus when they have to disengage and shift attention to the location of the neutral face.

ABMT and PT conditions of the app. Participants were assigned to either the ABMT or the PT condition of the app. Both experimenters and participants were blind to participants' assigned condition, and participants were blind to the purposes of the app. Participants sat comfortably at a table, were provided with an iPod Touch, and were instructed by the experimenter as follows:

> In this game two animated characters will appear on the screen. Shortly after, they will burrow into a hole. One of them will cause a path of grass to rustle behind it. With your finger, trace the path of the rustling grass, beginning from the burrow. Try to complete this task as quickly and as accurately as possible.

Next, experimenters demonstrated the swiping motion on the touch screen and provided participants with the opportunity to practice. The screen did not advance to the game until the swiping was correctly executed. Experimenters remained to answer any questions about the game. After each block of trials (40 trials), experimenters recorded the accrual of points and end-of-round feedback (see later discussion).

For every trial, two cartoon characters (sprites), one showing an angry expression and one showing a neutral/mildly positive expression, appeared simultaneously on the screen for 500 ms (see Fig. 2 for an example screenshot). Next, both sprites simultaneously "burrowed" into the grass field. In the ABMT condition, a trail of grass appeared in the location of the nonthreat character for every trial, whereas in the PT condition, a trail was equally likely to appear in the location of the angry or the neutral sprite. The grass remained until the participant responded (see Fig. 2). Paths were divided into separate "tufts" of grass (randomly varying between five and eight tufts), and when a tuft was correctly traced, it was illuminated.

Points were accrued on the basis of speed and accuracy (see the appendix for scoring details). The game provided participants with feedback after each trial by presenting one of three possible "jewels" that varied in color and accompanying sound: A red jewel with a low-pitch sound indicated slower response speed/less accuracy, a purple jewel with a medium-pitch sound indicated moderate response speed/moderate accuracy, and a gold jewel with a high-pitched sound indicated faster response speed/more accuracy (see the appendix for the detailed algorithm used to determine the feedback jewel). When errors were made (e.g., swiping the grass path toward rather than away from the burrow hole; not touching any portion of the grass path), a feedback sound was given (a high-pitched "Huh?"). Points were accrued on every trial because game play would not advance without a correct response.

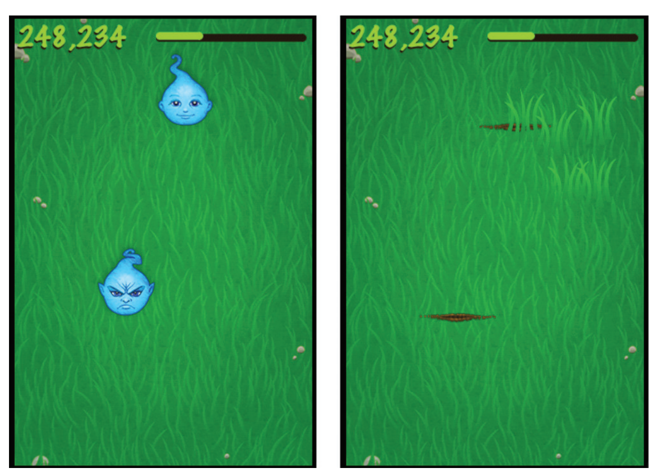

Fig. 2. Example screenshots of the app game play.

The short training condition consisted of 12 blocks of 40 trials for a total of 480 trials (25 min of game play with 20 min of breaks given consisting of a 10-min break after Round 160 and a 10-min break after Round 320). The long training condition consisted of 16 blocks of 40 trials for a total of 640 trials (45 min of game play with brief breaks given as needed). The total duration of experimental time (game play and breaks, equaling 45 min) was the same across both the short and the long training conditions. The number of short training trials was selected on the basis of ABMT studies that have shown significant reductions in threat bias, anxiety, and stress reactivity after a single session of 480 trials (Eldar & Bar-Haim, 2010; Klumpp & Amir, 2009) and multiple sessions of 480 trials (Eldar et al., 2012; Li, Tan, Qian, & Liu, 2008). Thus, the long training condition provided a number of training trials that exceeded the number that has been associated with significant effects of ABMT on anxiety- and stress-related outcomes in traditional ABMT studies.

Pre- and posttraining state anxiety. The state anxiety score was derived from the STAI (Spielberger, 1983). State anxiety was measured immediately prior to the app training and immediately after completing the app training.

Stress reactivity. After the app training and posttraining threat-bias assessment, the TSST was administered (Kirschbaum et al., 1993). The TSST included both a social-evaluative-threat task (giving a speech for 3 min after 3 min of preparation) and a lack-of-control task (3-min arithmetic task). Both tasks were videotaped and completed in front of two researchers who were described as judges. Participants were informed that their performance would be compared with the performances of others in the study and that a voice-frequency analysis and an analysis of nonverbal behaviors would be conducted. The TSST was not administered prior to attention training because acute stress may induce shifts in threat-related attention on the dot-probe task (Bar-Haim et al., 2010), thereby distorting the measurement of pretraining bias.

Anxious-behavior coding. Behaviors were coded as present or absent during the speech and the mental arithmetic stressors in 10-s time bins. Behaviors consisted of flight behaviors from Troisi (1999): looking down/away from the judge, closing the eyes, drawing the chin in toward the chest, crouching, and being still or freezing. In addition, nervous speech (e.g., "umm" or "hmm") and verbal expressions of frustration (e.g., profanities, groaning, or "Oh my goodness!") were coded. Videos were coded by four research assistants; for 15 of the videos, two research assistants completed the coding to assess reliability. Reliability (α = .78) was calculated using Krippendorff's alpha for nominal data (present/absent). These three subscores (anxious behavior, nervous speech, and verbal expressions of frustration) were analyzed separately and were summed into (a) a total score and (b) a total nervous-speech score comprising instances of nervous speech and verbal expressions of frustration. These two summary scores were arithmetic sums of all instances of these codes across the entire coding period (both the speech and the arithmetic task).

Self-report of mood. Self-reported mood was assessed before and after administration of the TSST. Using the 65-item POMS (McNair et al., 2003), participants indicated how well each adjective described their current mood; responses were made on a scale from 1 (*not at all*) to 5 (*extremely*). The POMS measures six mood states, including tension/anxiety, depression/dejection, anger/hostility, vigor/activity (reverse scored), fatigue/inertia, and confusion/bewilderment, for which scores are combined to generate a total negative-mood score.

Analytic approach

To test our central hypotheses that the ABMT condition of the app would reduce threat bias, subjective anxiety, and stress reactivity relative to the PT condition, and to explore dosage effects (short vs. long training), we conducted a series of 4 (Training Condition: short ABMT, short PT, long ABMT, long PT) × 2 (Gender) analyses of covariance (ANCOVAs). The ANCOVA approach allowed us to analyze for group differences in threat bias, subjective mood, and stress reactivity after the training procedure (posttraining assessment) while we controlled for differences in these measures at baseline (pretraining assessment or pre-TSST mood). This analytic approach, compared with a repeated measures analysis of variance, has greater power when treatment effects are assessed among randomly assigned groups (Van Breukelen, 2006).

Dependent variables included posttraining attentional bias, posttraining vigilance, posttraining disengagement, posttraining state anxiety, poststressor negative mood, and anxious behaviors and nervous speech during the stressor. Covariates comprised pretraining threat-bias measures, pretraining state anxiety, and prestressor negative mood. Behavior and speech during the TSST did not have a baseline measure to be used as a covariate.

Although almost half of the sample was 18 to 19 years of age, the age of the other half of the sample ranged from 20 to 50 years. Thus, we examined whether baseline mood and attention-bias scores differed across the broad age-groups: 18- to 19-year-olds (n = 45), adults in their 20s (n = 23), and adults 30 years of age and older (n = 8). Because sample sizes were uneven, we conducted analyses using nonparametric independent-samples Kruskal-Wallis tests. Several baseline measures—trait anxiety, vigilance, and attentional bias—differed across age-groups, and the oldest participants showed the lowest scores on these three variables (all ps < .05); thus, age in years was included as a covariate in all reported analyses.

One participant (in the long ABMT condition) was missing baseline threat-bias data as a result of too many error responses, and 7 participants refused to participate in the TSST (3 in the short PT, 1 in the short ABMT, 1 in the long PT, and 2 in the long ABMT conditions). These participants were excluded from analyses on the effects of training condition on these outcomes (i.e., 1 participant was excluded from threat-bias analyses and 7 participants were excluded from analyses with measures of stress reactivity obtained during the TSST).

Results

The four training-condition groups (short ABMT, short PT, long ABMT, and long PT) did not differ on any demographic variables or in baseline anxious and depressed mood (ethnicity/race: $p > .07$; all other ps > .32; see Table 1). The means and standard deviations of all pre- and posttraining threat-bias scores, self-reported anxiety, and measures of stress reactivity (self-reported mood before and after the stressor; anxious behaviors and nervous speech during the stressor) are presented in Table 2. In addition, we tested for training-condition differences in baseline measures of threat-bias scores. No significant group differences emerged.

Effects of training condition on threat bias

There was a significant main effect of training condition on attentional bias, $F(3, 65) = 3.15$, $p = .03$, $\eta^2 = .13$, and disengagement, $F(3, 65) = 4.94$, $p = .004$, $\eta^2 = .19$. The effect for vigilance did not reach significance, $F(3, 65) = 0.33$, $p = .80$, $\eta^2 = .01$. When we controlled for pretraining bias score and age, participants in the long-version ABMT condition ($M = -10.37$, $SE = 5.42$, 95% confidence interval (CI), = [–21.19, 0.45]) showed less biased attention to threat after training relative to those assigned to the long-version PT condition ($M = 6.99$, $SE = 4.56$, 95% CI = [–2.11, 16.09]) and to the short-version ABMT condition ($M = 6.86$, $SE = 4.61$, 95% CI = [–2.35, 16.07]; both ps < .02). Effects for disengagement mirrored those for attentional bias: Participants in the long-version ABMT condition ($M = -6.00$, $SE = 3.87$, 95% CI = [–13.73, 1.73]) showed less difficulty disengaging from threat after training relative to participants assigned to the long-version PT condition ($M = 5.25$, $SE = 3.26$, 95% CI = [–1.25, 11.75]) and to the short-version ABMT condition ($M = 8.58$, $SE = 3.29$, 95% CI = [2.02, 15.140]). Moreover, counter to our prediction, participants in the short-version ABMT condition showed greater difficulty disengaging from threat relative to participants assigned to the short-version PT condition ($M = -7.04$, $SE = 3.81$, 95% CI = [–14.66, 0.57]; $p = .01$).

Effects of training condition on anxious mood and stress reactivity

Figure 3 presents participants' state anxiety at the pre- and postassessments. There was a significant main effect of training condition, $F(3, 66) = 2.48$, $p = .07$, $\eta^2 = .10$. As predicted, controlled for pretraining subjective anxiety, participants in the ABMT condition reported reduced subjective anxiety immediately after training relative to those assigned to the PT condition, but this effect was found only for the short training conditions—short ABMT: $M = 35.10$, $SE = 1.40$, 95% CI = [32.31, 37.88]; short PT: $M = 39.42$, $SE = 1.61$, 95% CI = [36.22, 42.63]; $p = .045$. In addition, assignment to the short-version ABMT condition resulted in reduced anxiety after training relative to assignment to the long-version ABMT condition ($M = 39.19$, $SE = 1.64$, 95% CI = [35.91, 42.47]; $p = .06$) and to the long-version PT condition ($M = 39.93$, $SE = 1.36$, 95% CI = [37.22, 42.64]; $p = .02$).

Effects of reductions in threat bias on anxiety and stress reactivity

To test exploratory hypotheses that reductions in threat bias would predict reductions in anxiety and stress reactivity, we conducted a series of hierarchical multiple regressions in which age, gender, baseline measures of mood (preapplication state anxiety or prestressor mood), and baseline attention-bias score (either attentional-bias, vigilance, or disengagement score prior to attention training) were entered in the first step. We entered change in the corresponding attention-bias measure from pre-to posttraining in the second step and training condition (ABMT or PT) in the third step. Finally, the interaction between training condition and change in threat bias was entered in the fourth step. Analyses were conducted separately for the short and long trainings to allow for direct comparison between ABMT and PT conditions.[1]

Short training. Tests for moderation did not reach significance. However, regardless of training condition, reductions in attentional bias, $\beta = -0.52$, $\Delta F(1, 32) = 6.00$, $p = .02$, $\Delta R^2 = .11$, and reductions in difficulty disengaging from threat, $\beta = -0.54$, $\Delta F(1, 32) = 4.52$, $p = .04$, $\Delta R^2 = .09$, were associated with lower negative mood after the TSST. In addition, reductions in difficulty disengaging from threat were associated with less nervous speech expressed during the TSST, $\beta = -0.69$, $\Delta F(1, 29) = 6.20$, $p = .02$, $\Delta R^2 = .15$. Figure 4 depicts plots of these associations adjusted for the contribution of baseline attentional bias, age, and gender.

Long training. As predicted, changes in attentional bias from pre- to posttraining moderated the effects of training condition, $\beta = -1.07$, $\Delta F(1, 26) = 3.14$, $p = .04$ (one-tailed), $\Delta R^2 = .08$. Specifically, and as depicted in

Table 2. Pre- and Postassessment Anxiety, Depression Symptoms, Mood, and Behavior Scores for Each Training Condition

	Preassessment				Postassessment			
	Short Training		Long Training		Short Training		Long Training	
Measure	ABMT	PT	ABMT	PT	ABMT	PT	ABMT	PT
Attentional bias	0.97 (15.38)	4.93 (27.38)	–2.72 (51.47)	–5.69 (22.70)	5.69* (12.75)	–5.23 (19.40)	–8.28* (21.85)	2.73* (25.40)
Vigilance	–4.22 (18.64)	1.65 (24.53)	–12.06 (46.21)	–5.21 (29.29)	–2.00 (13.10)	–0.55 (17.32)	–6.79 (17.56)	–0.95 (18.46)
Disengagement	5.22 (17.98)	3.40 (16.86)	9.17 (19.90)	–0.47 (21.74)	7.67*# (10.72)	–4.75# (12.58)	–1.58* (15.56)	3.68* (18.63)
State anxiety	36.33 (11.64)	38.80 (10.49)	41.95 (10.21)	39.47 (8.70)	33.11† (99.74)	37.85† (9.81)	39.84† (10.49)	39.84† (8.48)
Mood (pre-TSST)					45.22 (12.64)	54.80 (24.71)	69.06 (25.41)	61.11 (20.67)
Mood (post-TSST)					77.28 (24.09)	76.95 (34.39)	81.41 (25.18)	73.11 (27.78)
Anxious behavior					94.44 (18.08)	82.83 (19.76)	89.20 (26.29)	87.61 (17.07)
Nervous speech					13.88 (5.58)	10.50 (5.45)	12.33 (7.64)	12.44 (8.18)

Note: The table presents means for each measure. Standard deviations are shown in parentheses. The Trier Social Stress Test (TSST) occurred at postassessment only. Main effects of training condition are indicated as follows: *Long ABMT < Long PT and Short ABMT; #Short ABMT > Short PT. †Short ABMT < Short PT, Long ABMT, and Long PT. ABMT = attention-bias-modification training; PT = placebo training.

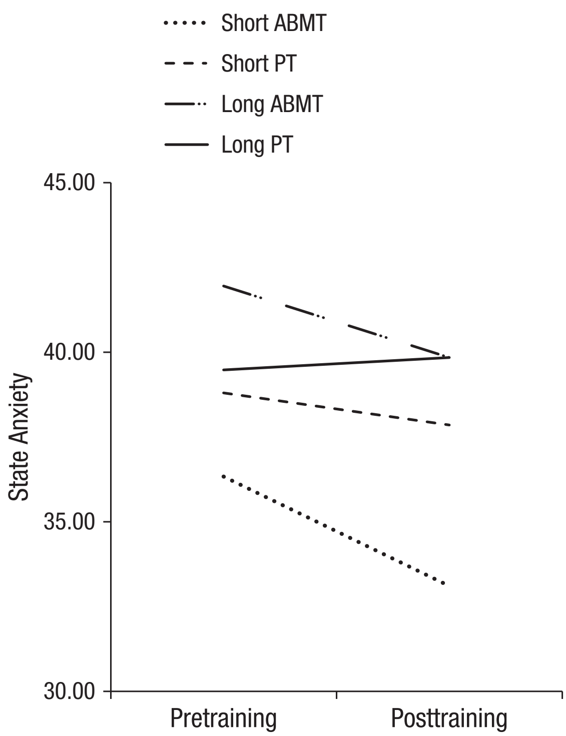

Fig. 3. Participants' state anxiety before and after training as a function of training condition. ABMT = attention-bias-modification training; PT = placebo training.

Figure 5, we found that participants assigned to the ABMT condition showed reduced negative mood after the TSST, but only if they also showed decreased vigilance after app play (only the decreased-vigilance line was significantly different from 0), $t(33) = 1.90$, $p = .03$ (one-tailed).

Discussion

The present study provides evidence that an alternative delivery strategy for ABMT—a gamified mobile app—shows transfer of benefits to independent, untrained lab-based measures of anxiety and stress reactivity after a single session of training. First, the app generalized to changes in the gold-standard measure of threat bias using the dot-probe task: Assignment to the long-version ABMT condition resulted in reduced attentional bias and difficulty disengaging relative to assignment to the PT condition and to the short-version ABMT condition. In addition, assignment to both the long and the short versions of the ABMT resulted in reductions in subjective and observed anxiety and stress reactivity. Taken together, results suggest that even after only a single session of play, this ABMT app may reduce and prevent acute stress responses and, therefore, act as what some researchers have termed a "cognitive vaccine" (in reference to depressed mood; see Browning, Holmes, Charles, Cowen, & Harmer, 2012; Holmes, Lang, & Shah, 2009). Crucial directions for future research include investigating the efficacy of more extended, more frequent, and briefer sessions of app use to reduce anxiety and stress; of neurocognitive mechanisms underlying treatment effects; and of the app when used outside the lab.

In the short training condition, assignment of participants to ABMT relative to PT resulted in reduced subjective state anxiety but, counter to predictions, was also associated with greater difficulty disengaging from threat measured via the dot-probe task. Although termed "short" training, 25 min of training (480 trials) is consistent with the duration of previous studies that have shown the efficacy of ABMT to reduce anxiety/stress in a single session (Eldar & Bar-Haim, 2010; Klumpp & Amir, 2009) or in multiple sessions (Eldar et al., 2012; Li et al., 2008). The significant effect of the short ABMT on subjective anxiety indicates that 25 min may represent an adequate amount of training to result in improved mood. However, because the short ABMT was also associated with greater difficulty disengaging from threat, rather than the increases in attentional control that other studies have documented (Amir, Beard, Taylor, et al., 2009; Amir, Weber, Beard, Bomyea, & Taylor, 2008), this finding suggests the influence of other potential mechanisms in the alleviation of anxious mood, such as exposure and habituation (Beard, 2011). The pursuance of this question is an important future direction for the ABMT research field as a whole, especially given that recent lab- and Internet-based trials have yielded equal treatment effects for ABMT conditions compared with PT conditions (e.g., Carlbring et al., 2012) and with conditions that train attention toward threat (e.g., Boettcher et al., 2013).

In this regard, for the short versions of the ABMT and PT conditions, participants who showed decreases in attentional bias and difficulty disengaging from threat showed less stress reactivity (observed anxious speech during the stressor and negative mood after the stressor). One possible explanation for this result is that mere exposure to threat stimuli when they compete with non-threat stimuli can result in reductions in behavioral threat bias for some individuals, a change that has anxiolytic and stress-reduction effects (Beard, 2011; Boettcher et al., 2013; Carlbring et al., 2012). In addition, the structured 10-min breaks during the short version of the app training may have contributed to the reduction of stress reactivity by giving participants time to consolidate effects of the training (Abend et al., 2013).

In contrast to findings for the short-version ABMT condition, for participants assigned to the long training condition of the app, ABMT relative to PT was associated with predicted reductions in attentional bias and difficulty disengaging. These findings are consistent with previous

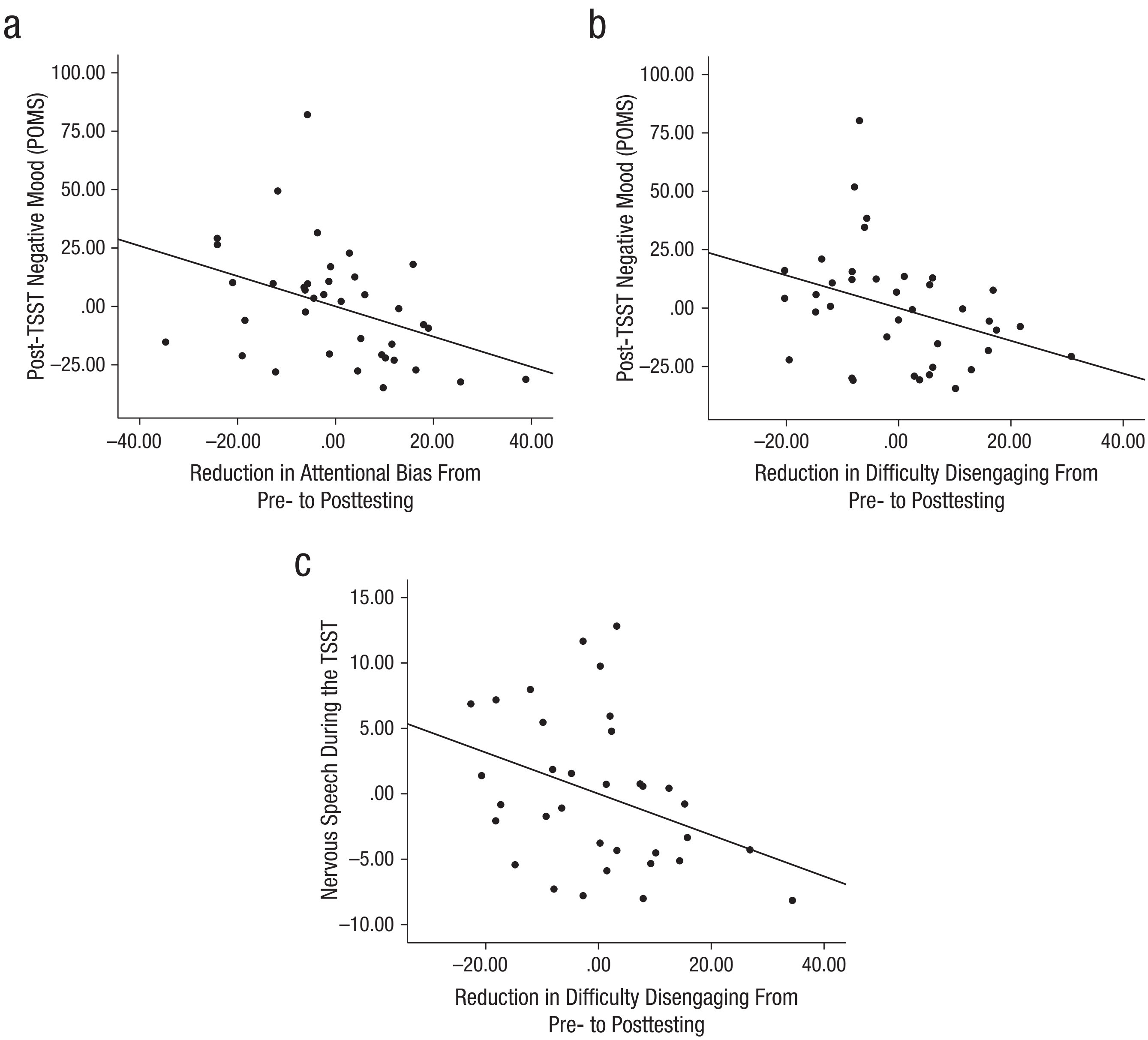

Fig. 4. Results: short version of the attention-bias-modification-training and placebo-training conditions. Scatter plots (with best-fitting regression lines) show associations between (a) reduction in attentional bias from pre- to posttraining and post-TSST negative mood (R^2 Linear = .158), (b) reduction in difficulty disengaging from threat from pre- to posttraining and post-TSST negative mood (R^2 Linear = .124), and (c) reduction in difficulty disengaging from threat from pre- to posttraining and nervous speech during the TSST (R^2 Linear = .130). TSST = Trier Social Stress Test; POMS = Profile of Mood States.

studies that have shown reductions in attentional bias and greater attentional control (ability to disengage from threat) after traditional ABMT (Hakamata et al., 2010). The massed presentation of trials in the long versus short versions of the training (i.e., without substantial breaks in the long version) may have contributed to these differential effects on the ability to disengage from threat; that is, massed presentation may be necessary for an acute shift in threat-bias performance during a single session. It is unclear whether massed presentation across multiple sessions is necessary to induce reductions in threat bias or whether shorter, more frequent sessions also can effectively reduce threat bias. This question is particularly important given that mobile applications are typically used in brief spurts (Purcell, 2011).

Results also showed that subjective mood was influenced in interaction with changes in vigilance: The long version of the ABMT resulted in reduced negative mood during the stressor, but this occurred only for those participants who showed decreases in vigilance after app play. This finding suggests that changes in automatic attentional capture, rather than later attentional hold, may

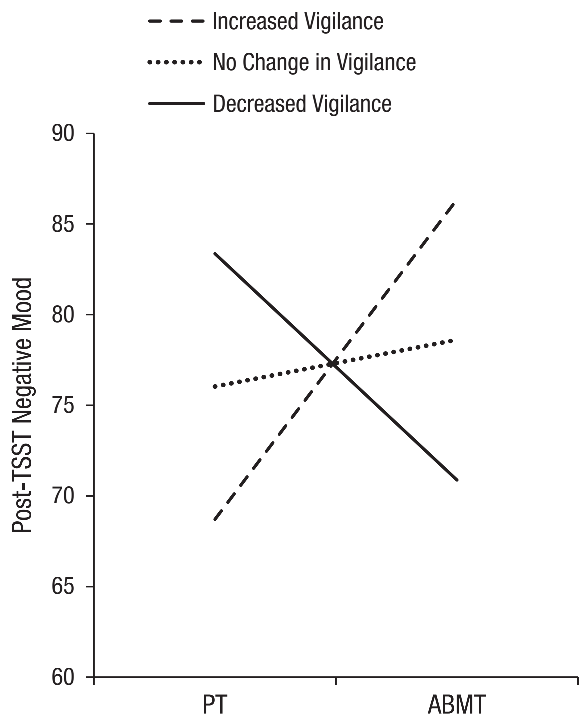

Fig. 5. Results: changes in vigilance as a function of long-version PT and ABMT conditions and post-TSST negative mood. PT = placebo training; ABMT = attention-bias-modification training; TSST = Trier Social Stress Test.

have a more direct influence on whether ABMT results in reductions in stress reactivity. Research that uses temporally sensitive measures, such as electroencephalography and scalp-recorded event-related brain potentials, may be particularly well suited to delineate the potential impact of earlier/automatic versus later/controlled neurocognitive changes on ABMT efficacy (Eldar & Bar-Haim, 2010; O'Toole & Dennis, 2012; Smith, Cacioppo, Larsen, & Chartrand, 2003). Indeed, our recent study has suggested that treatment-related reductions in early attentional capture (the N1 event-related-potential component) influence the impact of ABMT on stress reactivity (O'Toole & Dennis, under review). Such methodological additions may address growing concern about the context sensitivity of RT-based measures of threat bias, which can reduce measurement reliability (Brown et al., 2013). In the present study, participants showed variability in baseline measures of threat bias, although there were no significant group differences, thereby making it difficult to fully understand the degree to which the long version of the ABMT reduced threat bias. Larger sample sizes in future research would help increase confidence that variability at the baseline in measures of both threat bias and other individual differences (e.g., depression) is not influencing results. In addition, the development and validation of additional measures of threat bias is a crucial future direction for the field as a whole.

Given their potential to profoundly reduce barriers to mental-health services, it is important to clarify whether this and other kinds of ABMT apps can be conceptualized as cognitive vaccines that prevent or disrupt the trajectory of affective psychopathology (Browning et al., 2012). In this context, the concept of a cognitive vaccine suggests the ability to recalibrate habits of attention that, in the case of the threat bias, rigidly tune the individual toward threat and away from safety cues. This recalibration likely expands the type of information available for decision making and coping (Stout, Shackman, & Larson, 2013; Todd, Cunningham, Anderson, & Thompson, 2012) and, thus, serves to increase cognitive, affective, and behavioral flexibility. More flexibility may, in turn, disrupt the vicious cycle of anxiety in which threat bias heightens anxious arousal during stress, attention to threat is further facilitated, coping strategies become increasingly inflexible, and opportunities for disconfirmation of fear beliefs are minimized (Hofmann, 2007). If this flexibility could be maintained, it could both ameliorate anxiety severity and stress reactivity and bootstrap the efficacy of other treatments, such as cognitive behavioral therapy (Bechor et al., 2013; Rapee et al., 2013). Investigation of the impact of cognitive-bias-modification protocols on the efficacy of other treatments and on other affective-cognitive processes (Abend et al., 2013) is a crucial direction for future research. These questions highlight the exciting potential of mobile and gamified treatment approaches, particularly in a preventive or adjunctive treatment context.

Taken together, these results support the utility of an alternative delivery approach for ABMT and provide initial insights into dosage effects of a single session. However, several methodological limitations should be considered when interpreting our findings. First, participants in the present study were trait anxious but not clinically anxious. Although including a normatively anxious sample is a reasonable first research step and is highly relevant to questions about stress and anxiety prevention, it provides no direct evidence about whether the app is effective in clinical groups. Second, unlike traditional ABMT protocols that use multiple threat-related and neutral stimuli (whether words, faces, or complex emotional pictures), the current app used only one threat and one nonthreat cartoon character. This design may limit generalizability of the app, although some of the most robust findings of the present study were that assignment to the long-version ABMT condition resulted in reduced threat bias measured via the dot-probe task, thereby supporting the generalizability of the app to a novel and untrained context. Third, it remains unclear whether use of the app would be effective in nonlaboratory contexts, such as in the daily life of the individual, in which adherence cannot be as easily supervised (e.g., Carlbring et al., 2012; Enock & McNally, 2013).

Although the mobile format of the app presents methodological challenges, it simultaneously provides the tremendous benefit of instant access so that training can be completed anywhere (e.g., before attending a stressful event) with a low barrier to entry (a device with the Apple iOS mobile operating system) and in a form that is unobtrusive. Future research should investigate both the acceptability (willingness to use the app and adherence to treatment) and the efficacy of long-term app use. Moreover, the longevity of effects and the optimal number of trials and sessions requires focused research attention.

The present results showed that a single session of gamified ABMT effectively reduced threat bias, subjective anxiety, and stress reactivity. These findings add to the growing body of research that has demonstrated that evidence-based treatment mechanisms can be embedded into mobile (Amir & Taylor, 2012; Enock & McNally, 2013; Holmes et al., 2009) and gamified protocols, including those that target a range of cognitive biases, such as interpretation biases (Hallion & Ruscio, 2011; Mobini, Reynolds, & Mackintosh, 2012). These technologies are crucial targets for future research and hold promise in preventative, treatment, and self-help contexts.

Appendix

The total awarded score for a stage of play (40 rounds) is the sum of two scores: the speed and accuracy scores. If either the speed or the accuracy score is a rejection, the total score is a rejection.

Speed score

The speed score is a simple map-to-a-point value from the delay between the end of the jewel feedback animation and the moment the first finger touched the screen (*d*). Speed score is never a rejection, 18750 max 0.01, min 1, 1 – *d*3.

Accuracy score

There are two paths of interest, the drawn and target grass paths. (The grass path for the mean/untargeted face is ignored.) Each path is abstracted to three features: the centers of the bounding boxes; the widths of the bounding boxes, WD and WT; and the heights of the bounding boxes, HD and HT.

Next, some properties between the pair of drawn and target grass paths are calculated: the distance between the two centers divided by 480, CD; the absolute difference between the drawn and target bounding box widths, divided by 480, XD = ABS(WD – WT)480; and the absolute difference between the drawn and target bounding box heights, divided by 480, YD = ABS(HD – HT)480.

The accuracy score is considered a rejection if any of the following are true: (a) the signs (directions) of the drawn and target grass paths differ on either axis, that is, if a finger went left and the path went right; and (b) the width of the drawn path's bounding box is less than 10% of that of the target path's width or vice versa with regard to the height. If there is no rejection condition, the accuracy score is 16250 1 – CDD + XD + YD 3.

End-of-round feedback

The feedback at the end of the round (i.e., a trial) is determined by the round-level score, as shown in the following table:

Score	Jewel	Sound
Rejection	None	Error noise
< 21,000 points	Red	Low-pitch positive noise
21,000–24,999 points	Purple	Medium-pitch positive noise
≥ 25,000 points	Gold	High-pitch positive noise

Author Contributions

T.A.D. developed the study concept and both T.A.D. and L.J.O. contributed to the study design. Data collection, processing, and reduction was performed by L.J.O., and T.A.D. performed data analysis and interpretation. T.A.D. drafted the manuscript, and L.J.O. provided critical revisions prior to both authors approving the final version of the article for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Note

1. We also tested whether effects of training condition on anxiety and stress reactivity were mediated by changes in attention

biases by conducting a series of hierarchical multiple regressions using the PROCESS macro for SPSS (Hayes, 2013). This procedure tests the product of the coefficient for (α), the effect of the independent variable (training condition) to the mediator (change in attentional bias, vigilance, or disengagement), with (β), the effect of the mediator to the dependent variable (anxiety and stress reactivity) when the independent variable is taken into account. Corresponding pretraining measures for the dependent variable, along with age, gender, and baseline measures of mood, were entered as covariates. The 95% CI for the direct path ($\alpha\beta$) was calculated. There were no significant mediation effects.

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