Effects of Cognitive Bias Modification Training via Smartphones

Ranming Yang[1,2], Lixia Cui[1]*, Feng Li[1], Jing Xiao[1]*, Qin Zhang[1] and Tian P. S. Oei[3,4]

[1] Beijing Key Laboratory of Learning and Cognition and Department of Psychology, Capital Normal University, Beijing, China, [2] Criminal Justice College, China University of Political Science and Law, Beijing, China, [3] School of Psychology and CBT Unit, Toowong Private Hospital, University of Queensland, Brisbane, QLD, Australia, [4] Psychology Section, James Cook University, Singapore, Singapore

Background and Objectives: Negative cognitive biases have been linked to anxiety and mood problems. Accumulated data from laboratory studies show that positive and negative interpretation styles with accompanying changes in mood can be induced through cognitive bias modification (CBM) paradigms. Despite the therapeutic potential of positive training effects, few studies have explored training paradigms administered via smartphones. The current study aimed to compare the effectiveness of three different types of training programmes (cognitive bias modification-attention, CBM-A; cognitive bias modification-interpretation, CBM-I; attention and interpretation modification, AIM) administered via smart-phones by using a control condition (CC).

Methods: *Seventy-six* undergraduate participants with high social anxiety (Liebowitz Social Anxiety Scale, LSAS $\geq$ 30) were randomly assigned to four groups: CBM-A ($n = 20$), CBM-I ($n = 20$), AIM ($n = 16$), and CC ($n = 20$).

Results: The results showed that the effects of CBM training, CBM-I training, or AIM training vs. CC for attention yielded no significant differences in dot-probe attention bias scores. The CBM-I group showed significantly less threat interpretation and more benign interpretation than the CC group on interpretation bias scores.

Conclusions: The present results supported the feasibility of delivering CBM-I via smartphones, but the effectiveness of CBM-A and AIM training via smartphones was limited.

Keywords: cognitive bias modification, attention, interpretation, smartphones, social anxiety

INTRODUCTION

Research has shown that individuals who are extremely anxious tend to preferentially orient their attention toward threats, which influences their sensitivity to the environment (Fox and Beevers, 2016), and to interpret ambiguous information as threatening, which could reflect the down-stream effects of anxiety (White et al., 2016). While several psychotherapeutic procedures have been used to treat these biases (Tobon et al., 2011), recently, an increasing amount of research has focused on the use of Cognitive Bias Modification (CBM) procedures (Mackintosh et al., 2006; Wilson et al., 2006).

Researchers have developed experimental paradigms to modify cognitive biases, such as Cognitive Bias Modification-Attention (CBM-A) and Cognitive Bias Modification-Interpretation (CBM-I). Recent evidence has shown that CBM-A can reduce threatening attention bias

(Kuckertz and Amir, 2015) and that CBM-I can promote an optimism interpretive bias among anxious individuals (Rozenman et al., 2014; Clifton et al., 2016). Furthermore, these modifications were accompanied by a decline in the level of anxiety (Beard et al., 2011; Brosan et al., 2011). In addition, the positive outcomes of both CBM-A and CBM-I were replicated in people with anxiety problems (Rozenman et al., 2014; Clifton et al., 2016) and anxiety disorders (such as Social Phobia, Amir et al., 2009; Ogniewicz et al., 2014). Other studies (Timpano et al., 2009; Amir and Taylor, 2012) showed that people with anxiety also benefited from multi-session bias modification at a 4-month follow-up. Meta-analyses have examined the efficiency of CBM-A for anxiety and found an effect size of 0.61 (Hakamata et al., 2010). Another meta-analysis showed that CBM had a medium effect on biases ($g = 0.49$) and that the effect of CBM-I was stronger ($g = 0.81$) than that of CBM-A ($g = 0.29$) (Hallion and Ruscio, 2011). Beard et al. (2011) found that the attention and interpretation modification (AIM) treatment produced medium to large effects on social anxiety. A problem with using CBM alone or in combination was that participants reported that the procedures were tedious and repetitive. As a result, participants became tired and impatient (Beard et al., 2011). This could impair training adherence and lead to a high dropout rate.

With the increasing number of people who own a smartphone, interventions that incorporate smartphones have become increasingly popular in recent years (Garritty and El Emam, 2006). Carlbring et al. (2012) delivered CBM-A training via the internet, and the post treatment and 4-month follow-up results revealed a significant time effect on all measured dimensions (social anxiety scales, general anxiety, and depression levels, quality of life). Enock et al. (2014) demonstrated the feasibility of delivering CBM-A via smartphones in short, frequent sessions as well as the feasibility of conducting a relatively large, low cost, minimal contact, web-based RCT. Additionally, internet-based CBM-I had superior effects on interpretations (Salemink et al., 2014). The use of online CBM-I with anxious youth holds promise as an effective and easily administered component of treatment for child social anxiety (Reuland and Teachman, 2014). CBM training can be promoted along with the increasing number of medical-related applications available for smartphones. Moreover, as specialized mobile phones contain additional computing capabilities, they are likely to be the principal platforms for the development of the next generation of clinical applications (Boulos et al., 2011). Training in diverse locations could foster the generalization of clinical benefits. In addition to being popular and mobile, smartphone interventions also provide high accessibility for individuals seeking help and could reduce the cost of treatment (Kazdin and Rabbitt, 2013). The last advantage of delivering CBM through smartphones is that the approach could augment CBM's training effects. A high dose and frequency of training is a prerequisite for creating enduring changes in cognitive habits. Frequent training is easy with smartphones as participants can undergo training anywhere throughout the day.

In general, CBM training research is moving toward delivering longer interventions in naturalistic settings (MacLeod et al., 2009), but few CBM intervention studies have specifically targeted smartphones, and little is known about the effects of different CBM training programmes provided via smartphones. This is particularly true in China, where the penetration of smartphones is now widespread. With the advancement of modernization and economic progress, the rate of anxiety problems and anxiety disorders in China is increasing (Guo, 2000), yet treatment for anxiety problems is still not as well developed as in the Western world. The use of smartphones for the treatment of anxiety and anxiety-related problems needs to be tested in China. The Western literature reviewed above suggests that combined CBM is likely to be more effective than each programme alone. Thus, in this study, we hypothesized that AIM would produce better outcomes than either CBM-A or CBM-I alone and that these three conditions would have better outcomes than the control condition.

METHODS

Participants

One hundred four participants with scores above 30 on the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987) were selected from 490 undergraduate or graduate students at three different universities to participate in the study. In a pre-workshop evaluation conducted before the programme, we excluded those who scored 48 or higher on the LSAS and were likely to suffer from anxiety disorders or depression. Every participant read and signed an informed consent form. Our final sample included 76 Chinese undergraduate and graduate students (26 men and 50 women) with average age of 21.23 years old ($SD = 2.42$). The mean trait anxiety score for this group was 38.11 ($SD = 5.12$). This study was approved by the Institutional Review Board of Capital Normal University. A power analysis with the parameters 0.80, $p < 0.05$ and a medium effect size showed that the total sample size was 72 for an F-test among the factors of a 4×2 repeated measures ANOVA; thus, our sample of 76 participants was adequate.

Assessment Materials

Attention Bias Modification Assessment Task

The *Attention Bias Modification Assessment* Task consisted of a dot-probe task similar to that described in Macleod et al. (1986). In this paradigm, a fixation cross appeared for 500 ms, followed by the simultaneous presentation of two faces for 500 ms. One face appeared at the top of the screen, and the other appeared at the bottom. Immediately thereafter, a probe replaced one of the two faces. The probe was either an E or an F. The participants' task was to press one of two buttons on the screen as quickly as possible to indicate whether an E or F was presented. If the subject did not respond after 2,000 ms, the program automatically moved on to the next trial. The top and bottom positions of the probe letters and faces were randomly assigned, and the stimuli included 8 pairs of neutral/negative pictures, 8 neutral/neutral pictures and 8 neutral/neutral pictures (with no letters present). Each face was presented on the screen at the top and at the bottom four times. Of the total trials, 128 (2/3 of the total number) included 8 neutral faces and 8 negatives, with the probes appearing at an equal frequency in the position of negative face

FIGURE 1 | Example of a single trial for the dot-probe attention bias assessment.
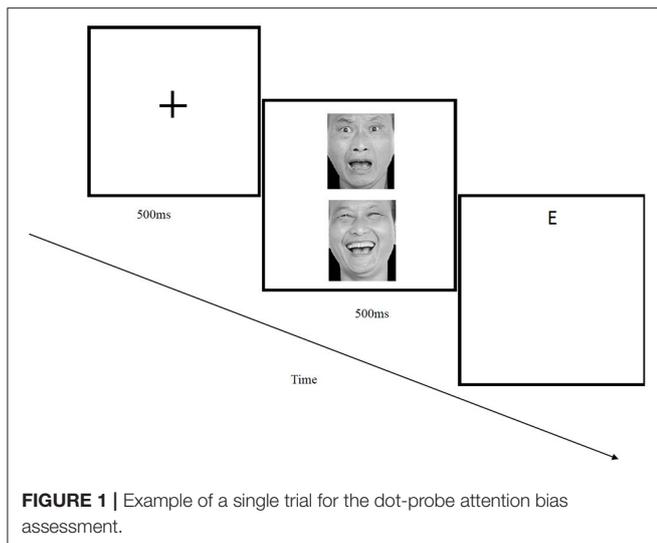
and neutral face [2 (negative face position: top or bottom) × 2 (probe type: E or F) × 4 (repetition)]; 32 trials (1/6 of the total number) included 8 neutral faces and 8 neutral faces, with the probes appearing at an equal frequency in each position of the neutral faces [2 (neutral face position: top or bottom) × 2 (probe type: E or F)]; and the remaining 32 trials (1/6 of the total number) were clueless trials (8 neutral face pairs × 2 (neutral face position: top or bottom) × 2 (probe type, E or F). Every test took ~5 min. All the face stimuli were from the Chinese Facial Affective Picture System (CFAPS; Wang and Luo, 2005) and were balanced across gender (male vs. female; See **Figure 1**). The program recorded automatically the participants' reaction time during the test.

Interpretation Bias Assessment

The CBM-I assessment procedure was identical to the Word Sentence Association Paradigm (WSAP; Beard and Amir, 2009). Each WSAP trial comprised four phases (See **Figure 2**). The participants completed 40 trials related to ambiguous social situations. The next trial began immediately after the participants responded. CBM-I ambiguous scenarios were based on those used by Mathews and Mackintosh (2000) and were revised to reflect Chinese students' situations. With reference to the 24 types of social contact situations described in the Liebowitz scale, we translated, rewrote and classified the situations into 20 types of social contact situations in accordance with the national context of China.

Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987)

The LSAS consists of 24 social situations (e.g., giving a speech) that socially anxious individuals commonly fear. For each situation, the participants rated their fear (0–3) and avoidance (0–3). The Chinese version of the LSAS has good reliability and validity (He and Zhang, 2004).

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

The State Trait Anxiety Inventory includes two parts with 20 items each. The first part is the STAI-S, which is used to assess

temporary unpleasant emotional experiences, such as tension, fear, worry and feelings of anxiety. The second part is the STAI-T, which is used to assess the tendency toward anxiety in an individual's relatively stable personality. The internal consistency reliability (Cronbach's α) of the Chinese versions of the STAI is 0.88, and the norm score for trait anxiety among Chinese undergraduates is 43.31 ($SD = 9.20$) (Li and Qian, 1995).

Procedure

See the flow of participants through each stage of the study in **Figure 3**. The participants completed the written informed consent form at the beginning of the pre-assessment. The consent form stated the purpose of this study: to evaluate the usefulness of smartphone based treatments for anxiety. However, it did not provide information regarding the rationale for either of the two conditions. The consent form also stated that the participants would be randomly assigned to one of the four groups: one receiving the cognitive bias modification-attention training, one receiving the cognitive bias modification-interpretation training, one receiving the attention and interpretation modification training, and the other group experiencing control conditions. The participants completed baseline assessments that included the STAI self-report measure, an attention bias assessment and an interpretation bias assessment. The pre-assessment took approximately 10 min. Following the pre-assessment, the participants were randomly assigned to one of the four conditions: CBM-A or CBM-I or AIM or CC. Eligible individuals visited an inter-linkage that outlined the training protocol and received instructions for accessing the training web page on their handheld devices.

CBM-A Training

The CBM-A training was similar to the attention bias assessment. The difference was that the probe (either the letter "E" or "F") only appeared at the location of the positive face. The stimuli used for the attention bias modification (ABM) task (dot probe task) were 40 positive-negative face pairs (i.e., happy and angry) and 40 neutral-neutral face pairs. During the CBM-A training, the participants completed 800 trials that comprised various combinations of probe type (E or F), probe position (top or bottom), and face type (positive or negative). Six hundred forty out of the 800 trials (i.e., 80% of the trials) included 40 positive faces and 40 negative faces, and the probe always replaced the positive face [2 (negative face position: top or bottom) × 2 (probe type: E or F) × 4 (repetition)]. Although, nothing specific to direct attention away from negative faces was provided, in 80% of the trials, the position of the negative face predicted the position of the probe (i.e., at the location opposite the disgust face). The remaining 160 trials (i.e., 20% of the trials) included 40 neutral-neutral face pairs [2 (neutral face position: top or bottom) × 2 (probe type: E or F)]. The training phrase lasted 40 min.

CBM-I Training

The CBM-I training was similar to the WSAP except that the participants received feedback on their responses. Specifically,
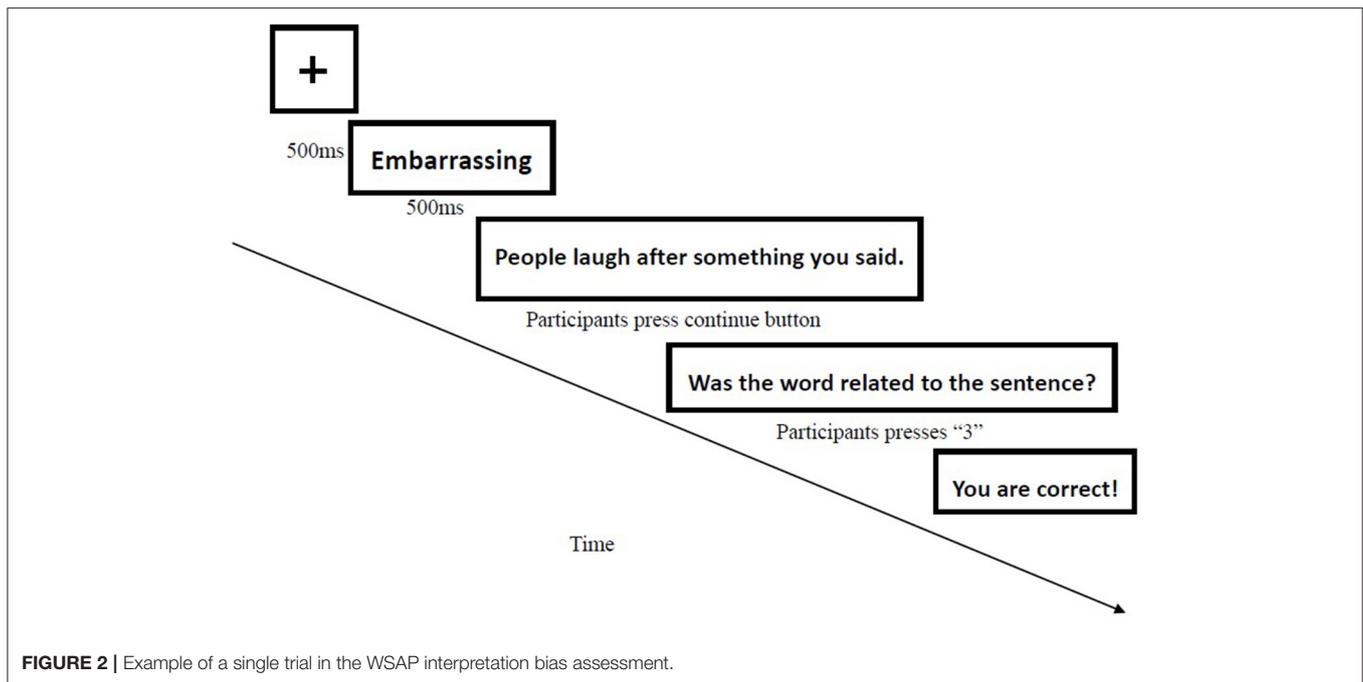
FIGURE 2 | Example of a single trial in the WSAP interpretation bias assessment.

after the participants responded regarding the relatedness of the word and the sentence presented, the smartphones provided feedback regarding their response. The participants received positive feedback when they endorsed benign interpretations or rejected threat interpretations in the ambiguous sentences, and they received negative feedback when they endorsed threat interpretations or rejected benign interpretations. This feedback aimed to strengthen a benign interpretation bias and eliminate the threat interpretation bias. The participants completed 160 training trials. The CBM-I session lasted approximately 40 min.

AIM Training

Participants in the AIM group received the same smartphone tasks as those in the CBM-A and CBM-I group. However, they only completed half the tasks for CBM-A and CBM-I. First, the participants received 400 CBM-A training trials. Of these trials, 320 (i.e., 80%) included 20 positive faces and 20 negative faces. The remaining 80 trials (i.e., 20%) included 20 neutral face pairs. The training phrase lasted 20 min. Then, the participants completed CBM-I training, which included 80 training trials. The CBM-I session lasted approximately 20 min. The entire AIM session lasted approximately 40 min.

CC Group

The CC group received the same smartphone tasks as the AIM group, but the process was different. In the probe task, when negative faces were presented to the CC group (i.e., positive-negative trials), the probe appeared with equal frequency in the position of the negative face and positive face. Therefore, 160 out of 400 trials (i.e., 40%) were positive-negative, with the probe following the negative face. The remaining 80 trials (i.e., 20%) included only neutral faces, as in the CBM-A. Neither the disgust face nor the neutral face had signal value regarding the location

of the probe. In the interpretation task, the CC group's task was identical to that of the CBM-I except that the feedback contingency was lowered to 50%. Specifically, the participants received positive feedback when they made threat interpretations on half of the trials and negative feedback when they made threat interpretations for the remaining half of the trials. This contingency was the same for benign interpretations. Thus, the control group was reinforced equally for making threat and benign interpretations. The CC was not intended to change the participants' interpretation significantly in either direction. The CC session lasted approximately 40 min.

After the CBM-A, CBM-I, AIM or CC training, the participants completed a post-assessment that was similar to the pre-assessment. All the participants were compensated at the rate of ¥40/h.

RESULTS

Preliminary Analyses

Descriptive statistics, including means and standard deviations (SD) for all outcome scores, are presented in **Table 1**. The participants assigned to the four groups did not differ in terms of demographic characteristics or baseline outcomes.

State Anxiety Scores

To examine whether the training was influenced by anxiety state, a 4×2 mixed-design ANOVA was performed on the state anxiety data, with group (CBM-A, CBM-I, AIM vs. CC) as between subjects and time (pre vs. post-tests) as the within-subjects factors. The results showed neither group nor Time main effects were significant ($p > 0.05$). The Group $\times$ Time interaction effect was also not significant ($p > 0.05$). The results indicated

FIGURE 3 | Flow chat of participants through each stage of the study.
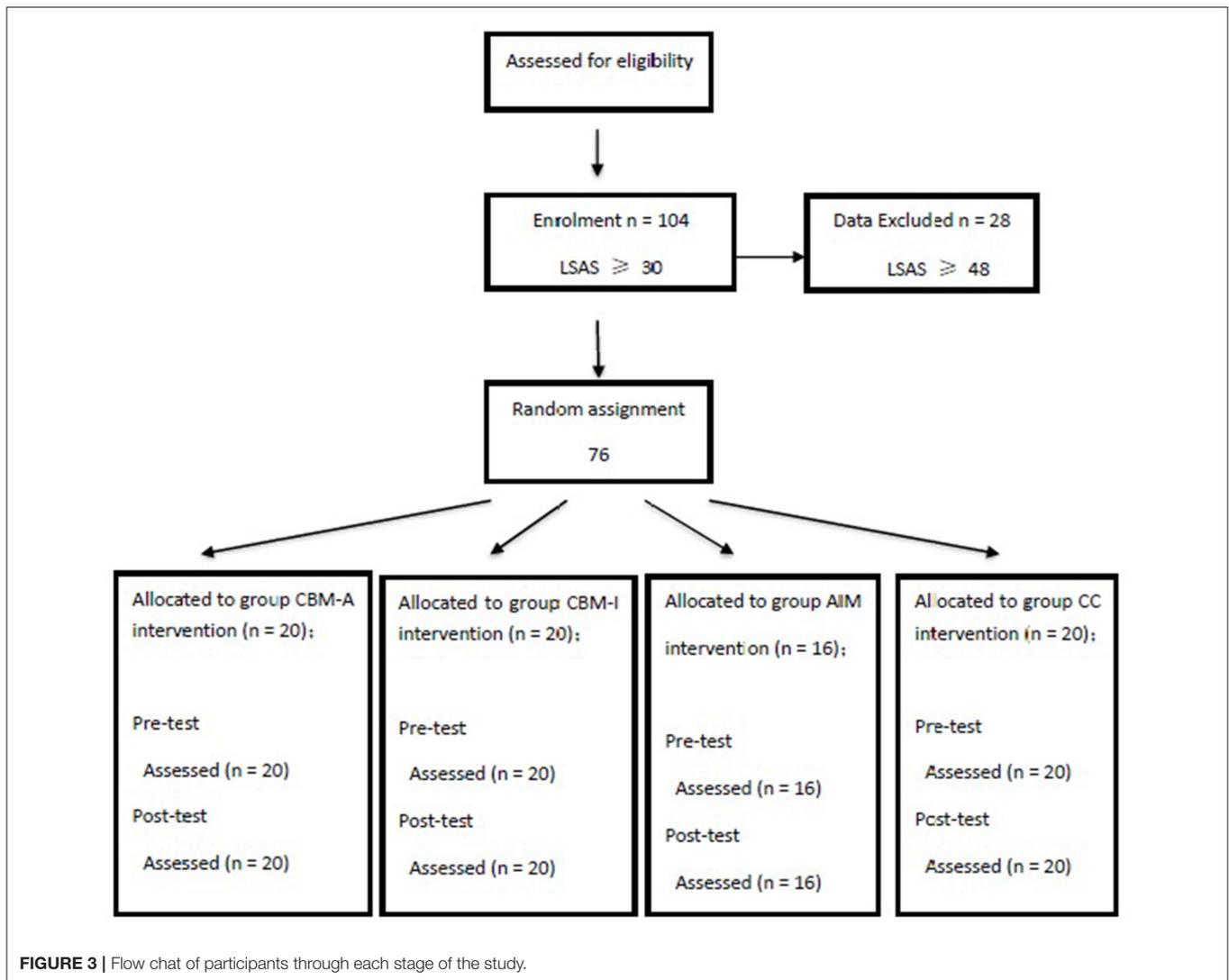
that the differences between the groups and the data before and after the training were not influenced by anxiety state.

Attention Bias

The mean attention bias scores for the four groups were presented in **Table 1**. The attention bias was the time subtracting the mean response time for neutral-location probes from the mean response for threat-location probes in negative-neutral trials. Higher scores suggested that there were more biases toward negative faces. The mixed 4×2 ANOVA with Group and Time factors yielded no significant main effects for the time [$F_{(1, 72)} = 6.01$, $p > 0.05$, $\eta^2 = 0.04$, 1-$\beta = 0.72$] and for the group [$F_{(3, 72)} = 7.15$, $p > 0.05$, $\eta^2 = 0.07$, 1-$\beta = 0.70$]. There was also not significant Time $\times$ Group interactions [$F_{(3, 72)} = 6.09$, $p > 0.05$, $\eta^2 = 0.05$, 1-$\beta = 0.75$].

Interpretation Bias

The participants' reaction time on the performance-based interpretation task was measured to examine how negative and

benign interpretations were related to the ambiguous sentences. This measurement revealed four types of reaction times: (a) acceptance of negative interpretations, (b) rejection of negative interpretations, (c) acceptance of benign interpretations, and (d) rejection of benign interpretations. Negative and positive bias indices were calculated for the reaction time data: negative bias = reaction times (reject negative—accept negative) and benign bias = reaction times (accept benign—reject benign). Higher scores suggested that there were more biases toward threat and benign interpretations, respectively. The lower the positive bias score, the more positive the interpretation was.

The mean negative and positive bias scores for the four groups over time are shown in **Table 1**. The mixed 4×2 ANOVA with group (CBM-A, CBM-I, AIM vs. CC) as the among-subjects factor and time as the repeated measure over time yielded significant main effects over time for negative bias [$F_{(1, 72)} = 11.07$, $p < 0.001$, $\eta^2 = 0.13$, 1-$\beta = 0.90$] and for positive bias [$F_{(1, 72)} = 10.01$, $p < 0.001$, $\eta^2 = 0.22$, 1-$\beta = 0.92$]. Significant group main effects were also found for negative bias

	CBM-A N = 20		CBM-I N = 20		AIM N = 16		CC N = 20	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SAI								
Pre-test	36.55	7.92	41.70	9.18	37.44	8.29	39.50	8.26
Post-test	35.70	10.14	40.00	9.39	37.81	8.69	45.25	11.72
ATTENTION BIAS								
Pre-test	1.28	24.70	1.11	22.33	1.25	31.53	1.19	31.02
Post-test	1.17	20.01	1.02	20.17	1.22	27.71	1.03	39.07
BENIGN INTERPRETATION								
Pre-test	−92.73	113.34	−102.73	145.54	−96.61	109.56	−95.15	103.65
Post-test	−117.22	140.21	−214.21	120.43	−116.56	118.64	−90.81	136.34
NEGATIVE INTERPRETATION								
Pre-test	271.22	204.10	269.27	190.23	246.06	211.67	256.38	321.53
Post-test	222.12	189.60	106.75	178.08	197.95	167.23	222.57	351.15

CBM-A, cognitive bias modification-attention; CBM-I, cognitive bias modification-interpretation; AIM, attention and interpretation modification; CC, control group.
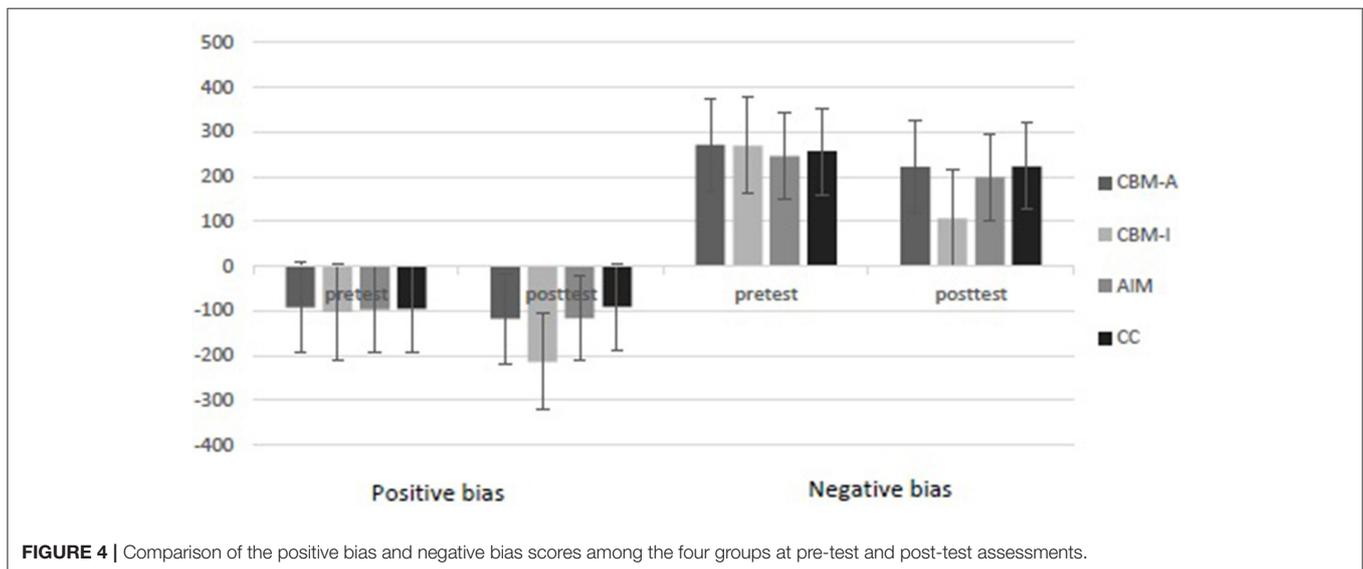

FIGURE 4 | Comparison of the positive bias and negative bias scores among the four groups at pre-test and post-test assessments.

$[F_{(3, 72)} = 9.17, p < 0.001, \eta^2 = 0.14, 1\text{-}\beta = 0.91]$ and for positive bias $[F_{(3, 72)} = 13.11, p < 0.001, \eta^2 = 0.18, 1\text{-}\beta = 0.92]$. Finally, significant Time × Group interactions were detected for negative bias $[F_{(3, 72)} = 12.22, p < 0.001, \eta^2 = 0.17, 1\text{-}\beta = 0.93]$ and for positive bias $[F_{(3, 72)} = 12.12, p < 0.001, \eta^2 = 0.10, 1\text{-}\beta = 0.94]$. For outcomes with significant Time × Group interactions, separate follow-up repeated-measures ANOVA models tested whether the groups differed significantly between pre- and post-test.

The mean positive bias scores for the four groups over time are shown in **Figure 4**. *Post-hoc* comparisons were conducted at the pre- and post-test. The results showed that there was no significant difference among the four groups at pre-test. At post-test, the positive bias scores in the CBM-I group were more negative and significantly higher than those in the CBM-A, AIM

and CC groups ($p < 0.001, d \geq 0.50, 1\text{-}\beta \geq 0.90$), but there was no significant difference among the CBM-A, AIM, and CC groups ($p > 0.05, d \leq 0.20, 1\text{-}\beta \geq 0.80$). *Post-hoc* comparisons between pre- and post-test were conducted within the four groups. The results showed that the positive bias scores at post-test were more negative and significantly higher than at pre-test ($p < 0.001, d = 0.55, 1\text{-}\beta = 0.92$) for the CBM-I group, but in the other three groups, there was no significant difference between pre- and post-test ($p > 0.05, d \leq 0.20, 1\text{-}\beta \geq 0.80$).

The mean negative bias scores for the four groups over time are shown in **Figure 4**. *Post-hoc* comparisons were conducted pre- and post-test. The results showed no significant difference among the four groups at pre-test. At post-test, the negative bias scores of the CBM-I group were significantly lower than those of the CBM-A, AIM and CC groups ($p < 0.001, d \geq 0.50, 1\text{-}\beta$

≥ 0.90). However, there was no significant difference among the CBM-A, AIM and CC groups ($p > 0.05$, $d \leq 0.20$, $1-\beta \geq 0.90$). *Post-hoc* comparisons between pre- and post-test were conducted within the four groups. The results showed that the negative bias score at post-test was significantly lower than that at pre-test ($p < 0.001$, $d = 0.57$, $1-\beta = 0.93$) in the CBM-I group, but in the other three groups, there was no significant difference between pre- and post-test ($p > 0.05$, $d \leq 0.20$, $1-\beta \geq 0.80$).

DISCUSSION

In this study, we tested the effects of one session of CBM-A training, CBM-I training, AIM training and CC on participants' attention and interpretation bias using a dot-probe task and the WSAP task delivered via smart-phone. The results showed that the effects of CBM training, CBM-I training, and AIM training vs. CC on attention yielded no significant differences in the dot-probe attention bias scores. The CBM-I group showed significantly less threat interpretation and more benign interpretation than did the CC group in the interpretation bias scores.

Why was there a change in interpretation bias with CBM-I but not with AIM, which contains the same training? A reason might be that the training trials did not reach the minimum requirements for the effect onset. The participants in the AIM group received the same smartphone task as the CBM-A and CBM-I participants. However, they only finished half the number of tasks that the CBM-A and CBM-I participants did. According to the current literature regarding the WSAP (Amir and Taylor, 2012), 110 trials each time was the minimum needed for effect onset. In the present study, the participants only finished 80 trials per session and may not have reached the minimum requirements for the effect onset.

In contrast to prior research reporting the effective modification of attention through dot-probe training in healthy samples (Hakamata et al., 2010; Hallion and Ruscio, 2011; Mogoase et al., 2014), we found no evidence that CBM-A or AIM provided via smartphones can modify attention biases via single-session training. This result agreed with recent studies that did not successfully modify attention bias through ABM programmes (e.g., Carlbring et al., 2012; Boettcher et al., 2013; Rapee et al., 2013). Furthermore, home-based training encouraged participants to focus their attention more closely, which facilitated the learning of the rule (i.e., that the probe was more likely to occur in the location opposite the threat cues); consequently, changes in performance may not necessarily indicate changes in the attention bias toward threat (Mogg et al., 2017). However, we think that these failures do not negate the theoretical and empirical basis of ABM. Effective changes in bias change depend on intensive empirical study of the precise task conditions and modes of delivery.

In our study, one possible reason for the failure to change attention bias was the participants' engagement level. In interviews conducted after the experiment, the participants told us that they could not understand how the ABM programme would help them to reduce anxiety and easily becoming upset. In contrast, they reported they could understand the interpretation modification programme well and that CBM-I training felt more fun and more engaging than CBM-A training.

Another possible reason was that the level of pre-training attention bias among the present participants was low, which led to no significant change in attention bias. The participants' pre-training attention bias score moderated the efficacy of CBM–A (Amir et al., 2011). In this study, the participants were normal and only had high social anxiety; the ABM procedures might exert a greater impact on participants with an existing attention bias toward threat, as predicted with clinical models.

This study has several limitations. First, the participants' engagement level in CBM-A training was low. Second, the training trials did not reach the minimum requirements for the effect onset. Third, the sample size was rather low. Although, we had sufficient power to detect the influences and effect sizes described in the results section, future studies with larger sample sizes are needed to support the conclusion presented in the present study. In future studies, we can improve our experiment in the following ways: First, we will try to combine fun elements with training via smartphones to improve the participants' engagement level in ABM. Second, we need to increase the number of training trials to reach the minimum requirements for the effect onset. Third, we will increase the number of subjects and improve the effect sizes.

This was only a preliminary study. The failures to consistently modify biased attention to threat highlights the need for more reliable means of achieving change in the target cognitive process. The present results only initially showed the feasibility of delivering CBM-I via smartphones, but the effectiveness of CBM-A and AIM training via smartphones was limited. Before longer interventions within naturalistic settings are conducted, some research on CBM interventions specifically delivered through smartphones is necessary.

ETHICS STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all the individual participants included in the study.

AUTHOR CONTRIBUTIONS

RY and LC the main writers and contributors of the paper and contributed equally to this work. LC the director of the research. FL took charge of the writing. JX revised the paper. TO finished the English editing. QZ contributed to the conception of the work and revised the paper.

ACKNOWLEDGMENTS

REFERENCES

Amir, N., and Taylor, C. T. (2012). Interpretation training in individuals with generalized social anxiety disorder: a randomized controlled trial. *J. Consult. Clin. Psychol.* 80, 497–511. doi: 10.1037/a0026928

Amir, N., Beard, C., Taylor, C. T., Klumpp, H., Elias, J., and Burns, M., et al. (2009). Attention training in individuals with generalized social phobia: a randomized controlled trial. *J. Consult. Clin. Psychol.* 77, 961–973. doi: 10.1037/a0016685

Amir, N., Taylor, C. T., and Donohue, M. C. (2011). Predictors of response to an attention modification program in generalized social phobia. *J. Consult. Clin. Psychol.* 79, 533–541. doi: 10.1037/a0023808

Beard, C., and Amir, N. (2009). Interpretation in social anxiety: when meaning precedes ambiguity. *Cognit. Ther. Res.* 33, 406–415. doi: 10.1007/s10608-009-9235-0

Beard, C., Weisberg, R. B., and Amir, N. (2011). Combined cognitive bias modification treatment for social anxiety disorder: a pilot trial. *Depress. Anxiety* 28, 981–988. doi: 10.1002/da.20873

Boettcher, J., Leek, L., Matson, L., Holmes, E. A., Browning, M., and Macleod, C., et al. (2013). Internet-based attention bias modification for social anxiety: a randomized controlled comparison of training towards negative and training towards positive cues. *PLoS ONE* 8:e71760. doi: 10.1371/journal.pone.0071760

Boulos, M. N., Wheeler, S., Tavares, C., and Jones, R. (2011). How smart-phones are changing the face of mobile and participatory healthcare: an overview, with example from eCAALYX. *Biomed. Eng. Online* 10:24. doi: 10.1186/1475-925X-10-24

Brosan, L., Hoppitt, L., Shelfer, L., Sillence, A., and Mackintosh, B. (2011). Cognitive bias modification for attention and interpretation reduces trait and state anxiety in anxious patients referred to an out-patient service: results from a pilot study. *J. Behav. Ther. Exp. Psychiatry* 42, 258–264. doi: 10.1016/j.jbtep.2010.12.006

Carlbring, P., Apelstrand, M., Sehlin, H., Amir, N., Rousseau, A., and Hofmann, S. G., et al. (2012). Internet-delivered attention bias modification training in individuals with social anxiety disorder - a double blind randomized controlled trial. *BMC Psychiatry* 12:66. doi: 10.1186/1471-244X-12-66

Clifton, J. L., Hedley, S., Mountier, E., Tiszai, B., and Grimshaw, G. M. (2016). Practice makes perfect: training the interpretation of emotional ambiguity. *Cogn. Emot.* 30, 1–15. doi: 10.1080/02699931.2015.1020768

Enock, P. M., Hofmann, S. G., and Mcnally, R. J. (2014). Attention bias modification training via smart-phone to reduce social anxiety: a randomized, controlled multi-session experiment. *Cogn. Ther. Res.* 38, 200–216. doi: 10.1007/s10608-014-9606-z

Fox, E., and Beevers, C. G. (2016). Differential sensitivity to the environment: contribution of cognitive biases and genes to psychological wellbeing. *Mol. Psychiatry* 21, 1657–1662. doi: 10.1038/mp.2016.114

Garritty, C., and El Emam, K. (2006). Who's using PDAs? Estimated of PDA use by health care providers: a systematic review of surveys. *J. Med. Int.* 8:e7. doi: 10.2196/jmir.8.2.e7

Guo, X. W. (2000). Study on cause of social anxiety. *Explor. Psychol.* 73, 55–58. doi: 10.3969/j.issn.1003-5184.2000.01.012

Hakamata, Y., Lissek, S., Bar-Haim, Y., Britton, J. C., Fox, N. A., and Leibenluft, E., et al. (2010). Attention bias modification treatment: a meta-analysis toward the establishment of novel treatment for anxiety. *Biol. Psychiatry* 68, 982–990. doi: 10.1016/j.biopsych.2010.07.021

Hallion, L. S., and Ruscio, A. M. (2011). A meta-analysis of the effect of cognitive bias modification on anxiety and depression. *Psychol. Bull.* 137, 940–958. doi: 10.1037/a0024355

He, Y. L., and Zhang, M. Y. (2004). Psychometric investigation of Liebowitz social anxiety scale. *J. Diagn.* 3, 89–93. doi: 10.1371/journal.pone.0070235

Kazdin, A. E., and Rabbitt, S. M. (2013). Novel models for delivering mental health services and reducing the burdens of mental illness. *Clin. Psychol. Sci.* 194, 170–191. doi: 10.1177/2167702612463566

Kuckertz, J. M., and Amir, N. (2015). Attention bias modification for anxiety and phobias: current status and future directions. *Curr. Psychiatry Rep.* 17, 1–8. doi: 10.1007/s11920-014-0545-x

Li, W. L., and Qian, M. Y. (1995). Revision of the state-trait anxiety inventory with sample of Chinese college students (in Chinese). *Actacentiarum Naturalum Universitis Pekinesis* 31, 108–114.

Liebowitz, M. R. (1987). Social phobia. *Mod. Probl. Pharmacopsychiatry* 22, 141–173. doi: 10.1159/000414022

Mackintosh, B., Mathews, A., Yiend, J., Ridgeway, V., and Cook, E. (2006). Induced biases in emotional interpretation influence stress vulnerability and endure despite changes in context. *Behav. Ther.* 37, 209–222. doi: 10.1016/j.beth.2006.03.001

MacLeod, C., Koster, E. H., and Fox, E. (2009). Whither cognitive bias modification research? Commentary on the special section articles. *J. Abnormal Psychol.* 118, 89–99. doi: 10.1037/a0014878

Macleod, C., Mathews, A., and Tata, P. (1986). Attentional bias in emotional disorders. *J. Abnorm. Psychol.* 95, 15–20. doi: 10.1037/0021-843X.95.1.15

Mathews, A., and Mackintosh, B. (2000). Induced emotional interpretation bias and anxiety. *J. Abnorm. Psychol.* 109, 602–615. doi: 10.1037/0021-843X.109.4.602

Mogg, K., Waters, A. M., and Bradley, B. P. (2017). Attention bias modification (abm): review of effects of multisession abm training on anxiety and threat-related attention in high-anxious individuals. *Clin. Psychol. Sci.* 5, 698–717. doi: 10.1177/2167702617696359

Mogoase, C., David, D., and Koster, E. H. (2014). Clinical efficacy of attentional bias modification procedures: an updated meta-analysis. *J. Clin. Psychol.* 70, 1133–1157. doi: 10.1002/jclp.22081

Ogniewicz, A. S., Dugas, M., Langlois, F., Gosselin, P., and Koerner, N. (2014). An adapted word-sentence association paradigm for generalized anxiety and worry: assessing interpretation bias. *J. Exp. Psychopathol.* 5, 457–476. doi: 10.5127/jep.039013

Rapee, R. M., Macleod, C., Carpenter, L., Gaston, J. E., Frei, J., and Peters, L., et al. (2013). Integrating cognitive bias modification into a standard cognitive behavioral treatment package for social phobia: a randomized controlled trial. *Behav. Res. Ther.* 51, 207–215. doi: 10.1016/j.brat.2013.01.005

Reuland, M. M., and Teachman, B. A. (2014). Interpretation bias modification for youth and their parents: a novel treatment for early adolescent social anxiety. *J. Anxiety Disord.* 28, 851–864. doi: 10.1016/j.janxdis.2014.09.011

Rozenman, M., Amir, N., and Weersing, V. R. (2014). Performance-based interpretation bias in clinically anxious youths: relationships with attention, anxiety, and negative cognition. *Behav. Ther.* 45, 594–605. doi: 10.1016/j.beth.2014.03.009

Salemink, E., Kindt, M., Rienties, H., and Hout, M. V. D. (2014). Internet-based cognitive bias modification of interpretations inpatients with anxiety disorders: a randomised controlled trial. *J. Behav. Ther. Exp. Psychiatry* 45, 186–195. doi: 10.1016/j.jbtep.2013.10.005

Spielberger, C. D., Gorsuch, R., Lushene, R., Vagg, P., and Jacobs, G. (1983). *Manual for the State-Trait Anxiety Inventory (From Y).* Palo Alto, CA: Consulting Psychologists Press.

Timpano, K. R., Buckner, J. D., Richey, J. A., Murphy, D. L., and Schmidt, N. B. (2009). Exploration of anxiety sensitivity and distress tolerance as vulnerability factors for hoarding behaviors. *Depress. Anxiety* 26, 343–353. doi: 10.1002/da.20469

Tobon, J. I., Ouimet, A. J., and Dozois, D. J. A. (2011). Attentional bias in anxiety disorders following cognitive behavioral treatment. *J. Cogn. Psychother.* 25, 114–129. doi: 10.1891/0889-8391.25.2.114

Wang, Y., and Luo, Y. J. (2005). Standardization and assessment of college students' facial expression of emotion. *Chinese J. Clin. Psychol.* 4, 396–398. doi: 10.3969/j.issn.1005-3611.2005.04.006

White, L. K., Suway, J., Pine, D., and Fox, N. (2016).The cognitive and emotional effects of cognitive bias modification in interpretations in behaviorally inhibited youth. *J. Exp. Psychopathol.* 70, 449–510. doi: 10.5127/jep.053615

Wilson, E. J., Macleod, C., Mathews, A., and Rutherford, E. M. (2006). The causal role of interpretive bias in anxiety reactivity. *J. Abnorm. Psychol.* 115, 103–111. doi: 10.1037/0021-843X.115.1.103