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Impact of Imagery-Enhanced Interpretation Training on Offline and Online Interpretations in Worry

Ya-Chun Feng[a], Charlotte Krahé[a1], Frances Meeten[a2], Alexander Sumich[b, c], C. L. Michelle Mok[a3] and Colette R. Hirsch[a, d]

[a] Department of Psychology, King's College London, Institute of Psychiatry, Psychology and Neuroscience, UK

[b] Division of Psychology, School of Social Sciences, Nottingham Trent University, Nottingham, UK

[c] Department of Psychology, Auckland University of Technology, Auckland, New Zealand

[d] Centre for Anxiety Disorders and Trauma, South London and Maudsley NHS Foundation Trust, UK

Correspondence: Dr Colette Hirsch, Department of Psychology, Institute of Psychiatry, Psychology and Neuroscience, King's College London, De Crespigny Park, London SE5 8AF, Email: colette.hirsch@kcl.ac.uk

[1]Present address: Department of Psychological Sciences, University of Liverpool, Liverpool, UK.
[2]Present address: School of Psychology, University of Sussex, Falmer, Brighton, UK.
[3]Present address: University Hospital Lewisham, Lewisham High St, Lewisham, London, UK.

Abstract

Worry and rumination are forms of repetitive negative thinking (RNT) that are maintained by negative interpretations and a predominance of abstract, verbal thinking. Hence, facilitating more positive interpretations and imagery-based thinking in combination may reduce RNT. Study 1 administered interpretation training with and without enhanced imagery, and an active control condition (designed not to change interpretations), in individuals with high levels of RNT (worry and/or rumination). Combining interpretation training with sustained imagery resulted in the highest levels of positive interpretation bias using an offline test of interpretation bias (when individuals have time to reflect). Study 2 investigated whether imagery-enhanced interpretation training influences online interpretations when ambiguous information is first encountered, indexed by reaction times and amplitude of the N400 event-related potential, as well as enhances offline positive interpretations in high worriers. It also examined whether imagery-enhanced interpretation training reduces negative thought intrusions associated with worry. Both online (reaction time) and offline interpretations were more positive following imagery-enhanced interpretation training, and negative thoughts were reduced, compared to the active control. However, no differences emerged on neurophysiological markers during the online task. Hence, brief interpretation training encompassing sustained imagery modifies online and offline interpretations, but further training may be required to impact upon neurophysiological measures.

Keywords: cognitive bias modification of interpretation (CBM-I); mental imagery; interpretation bias; repetitive negative thinking; worry; event-related potentials (ERP).

Impact of Imagery-Enhanced Interpretation Training on Offline and Online Interpretations in Worry

Worry is a form of repetitive negative thinking (RNT), often about potential negative future events, which is prevalent across a range of psychological disorders, as well as in the wider population. Uncontrollable worry about multiple topics is the cardinal feature of generalised anxiety disorder (GAD; APA, 2013). As well as worry, RNT includes other types of maladaptive thinking such as rumination, obsessional thinking, and post-event processing. Rumination is perhaps the most similar to worry, and both worry and rumination co-occur across clinical and non-clinical populations (Krahé, Whyte, Bridge, Loizou, & Hirsch, 2019). Furthermore, although the temporal focus of pathological rumination (past orientated) and worry (future oriented) differ, the processes are proposed to operate in a similar manner across disorders (Ehring & Watkins, 2008; Hirsch et al., 2018). Understanding the underlying cognitive processes that maintain these types of negative thinking is vital for designing new interventions to ameliorate pathological RNT. The present paper reports two studies that test the effects of a brief training designed to target unhelpful cognitive biases in individuals with high levels of RNT (Study 1) and worry in particular (Study 2).

A number of cognitive processes have been proposed to contribute to the maintenance of worry. Hirsch and Mathews' (2012) model of pathological worry posits a key role for relatively bottom-up cognitive biases, such as habitual attentional biases to threat and a bias to generate negative interpretations of ambiguous information (termed interpretation bias), which can trigger bouts of worry. For example, the scenario "As you submit your report to your manager, you know what she will think." can be interpreted as "She will think it is good/bad.", and if the negative interpretation is generated, this will increase the likelihood that negative thoughts and worry will follow. These thoughts, in turn, will provide more opportunities for ambiguity to be interpreted negatively. Hirsch and Mathews (2012) further propose that these cognitive biases, combined with dysfunctional top-down allocation of attentional control resources, result in a tendency to experience protracted worry in verbal form with little imagery (Hirsch, Hayes, Mathews, Perman, & Borkovec, 2012). Such verbal processing, compared to thinking in mental images, is thought to contribute to the abstract and over-general nature of worry (e.g., "What if I keep doing poorly at everything I try?"), making it difficult to pinpoint and resolve worries and perpetuating intrusive negative thoughts. Thus, bottom-up cognitive biases, such as interpretation bias, may initiate and maintain streams of worry, and the dominant verbal mentation (thinking) style may maintain it further. These biases are also present in other disorders characterized by excessive RNT, such as depression (e.g., Everaert, Koster, Derakshan, 2012), and can be considered to represent a transdiagnostic process that maintains pathological RNT (Hirsch, Meeten, Krahé, & Reeder, 2016; Hirsch et al., 2018).

The Relationship between Interpretation Bias and Repetitive Negative Thinking

Individuals with GAD or depression demonstrate negative interpretation biases (Anderson et al., 2012; Butler & Mathews, 1983; Everaert et al., 2012; Everaert, Podina, & Koster, 2017; Eysenck, Mogg, May, Richards, & Mathews, 1991; Mathews, Richards, & Eysenck, 1989; Mogg, Baldwin, Brodrick, & Bradley, 2004; Nunn, Mathews, & Trower, 1997). RNT, in the form of worry and rumination, is an integral characteristic of GAD and depression. RNT is associated with negative interpretation bias in the general population, as well as in individuals with GAD or depression (Krahé et al., 2019). The causal role of interpretation bias in maintaining RNT is supported by single-session designs (Hayes, Hirsch, Krebs, & Mathews, 2010; Hertel, Mor, Ferrari, Hunt, & Agrawal, 2014; Hirsch, Hayes, & Mathews, 2009). For example, participants with GAD who were trained in to generate more positive interpretations reported fewer negative thought intrusions during a lab-based worry task following a single session of training, than did control participants (Hayes et al. 2010).

Furthermore, using a multi-session design (i.e., repeated training sessions over several weeks), Hirsch et al. (2018) investigated whether both worry and rumination are maintained by negative interpretation biases in the longer term. Participants with GAD or depression were trained to develop a more positive interpretation bias over 10 sessions of interpretation training, completed over three weeks. When compared to an active control condition, which presented the same materials as the training but left ambiguity unresolved, the positive interpretation training reduced trait levels of worry and rumination across diagnostic groups at one-month follow-up, thus supporting the proposal that both forms of RNT are maintained by negative interpretation bias. Whilst encouraging, cognitive biases are thought to interact to maintain RNT in psychopathology (Everaert et al., 2012; Hirsch, Clark & Mathews, 2006). Hence, interpretation training that also targets other cognitive processes may augment its effects on RNT.

The Role of Imagery in Repetitive Negative Thinking

Prior research has shown that pathological worry is dominated by verbal processing with only infrequent and brief imagery (Freeston, Dugas, & Ladouceur, 1996; Hirsch et al., 2012). This lack of imagery may contribute to the abstract (as opposed to concrete) generalized thinking found in both worry and rumination (Watkins, 2008), and anxiety and depression more broadly (Stöber, 2000). Such abstract thinking may hinder problem-solving and maintain the salience of worry and ruminative thoughts. Furthermore, worrying in verbal as compared to imagery form promotes an attentional bias to focus on threat (Williams, Mathews & Hirsch, 2014), and increases subsequent negative thought intrusions (Stokes & Hirsch, 2010; Hirsch, Perman, Hayes, Eagleson, & Mathews, 2015). Taken together, these findings suggest that attenuating verbal processing by supporting the use of mental imagery may be a promising target for reducing worry and rumination. Given the proposed role of cognitive biases such as interpretation bias in initiating and maintaining worry, combining interpretation training with imagery-based mentation may augment the impact on worry and other forms of RNT.

The initial studies using interpretation bias training (e.g. Mathews & Mackintosh, 2000) and those that examined this training effect in worry (Hayes et al., 2010; Hirsch et al., 2009) did contain some use of imagery in the training instructions. In particular, participants were instructed to imagine themselves in the scenarios they read. However, in these studies there was no formal training in use of imagery, or assessment of use of imagery. Facilitating the use of imagery during interpretation training has been shown to induce positive mood post-interpretation training more effectively than verbal training alone (verbal training asked participants to focus on the meaning of the words and did not include any imagery instructions), and furthermore facilitates positive feelings about new ambiguous events (Holmes, Mathews, Dalgliesh, & Mackintosh, 2006). Holmes, Lang and Shah (2009) compared verbal (no imagery instructions) and imagery- based interpretation bias training in a non-selected sample. Participants were trained to engage in the positive interpretation bias training in imagery form, or by focusing on the verbal meaning of the training scenarios. As compared to verbal-based interpretation bias training, Holmes, Lang and Shah (2009) found that participants in the imagery condition made more positive interpretations compared to the verbal condition. These studies provide initial support for promoting mental imagery in enhancing the effects of interpretation training. This is likely to be particularly important for individuals who experience high levels of RNT, where RNT is characterized by abstract verbal thinking with little imagery. Yet, to our knowledge, no studies have examined the combined effect of imagery and interpretation training in individuals with high levels of RNT in general, or worry in particular. Therefore, Study 1 compared the interpretation training with minimal instructions to imagine oneself in the described situations as per Mathews and Mackintosh (2000) with another imagery-enhanced interpretation training where participants were trained to generate vivid mental images and had prolonged time to imagine positive endings.

Study 1

Given the hypothesized role for interpretation biases and verbal processing in maintaining worry (Hirsch & Mathews, 2012), and in keeping with

Hirsch et al. (in press), who propose that this model may equally apply to rumination, we conducted a single-session study to investigate the hypothesis that imagery-enhanced interpretation training would result in more positive interpretations of ambiguous information, as measured by the recognition test (Mathews & Mackintosh, 2000), compared to interpretation training without specific imagery enhancement[4]. Although this study focused on the effect of imagery-enhanced interpretation training, it was not designed to test the potential mechanisms that may facilitate greater training effects. Rather, it aimed to examine a more general question of whether the enhanced imagery training that involved multiple components would facilitate interpretation training effects, compared with the training without these components. The components involved in the imagery-enhanced training were self-generated positive outcomes, explicit instructions to generate positive outcomes, and positive imagery. These components are likely to each contribute to training effects and this is discussed in the general discussion section. A secondary hypothesis was that both the interpretation training conditions would be associated with greater positive interpretation bias compared to an active control condition in which ambiguity was left unresolved.

Methods

Design

Participants were randomly allocated to one of the three conditions: (1) cognitive bias modification of interpretation (CBM-I) without extended mental

[4] Both conditions also included an RNT induction immediately prior to training, as in Hirsch et al. (2018); see RNT induction phase below.

imagery (CBM_RNT); (2) imagery-enhanced CBM-I (CBM_ENH); or (3) an active control (CON) condition, which did not aim to train a particular interpretation bias. Interpretation bias was assessed before and after a single session of training or an active control. Self-report measures of levels of worry and mood were completed prior to completing the CBM-I /control session. The study was approved by King's College London Research Ethics Committee.

Participants

Participants in this study were recruited as part of a larger study described in Hirsch et al. (in press) and provided informed consent. Participants with high levels of worry or rumination were recruited from the community and the university via online advertisements and circular emails. All were fluent in English, with normal or corrected hearing, and aged between 18 and 65 years old. They were initially screened for levels of worry or rumination using the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) and the Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991). Participants scoring 62 or above on the PSWQ and/or 63 or above on the RRS were invited, provided they also met inclusion criteria outlined below. Inclusion criteria were scoring 10 or above on the Generalized Anxiety Disorder 7-item scale (GAD-7; Spitzer, Kroenke, Williams, & Löwe, 2006) for anxiety and/or the Patient Health Questionnaire 9 (PHQ-9; Kroenke & Spitzer, 2002) for depression[5].

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[5] The cut-off score on the PSWQ was based on research indicating that a score of 62 achieved high specificity as a screening instrument for GAD (0.86; Behar, Alcaine, Zuellig, & Borkovec, 2003). The cut-off score on the RRS was based on previous research into depressive rumination reporting mean values of *M* = 63 in samples of participants with depression (Papageorgiou & Wells, 2003; Pearson, Brewin, Rhodes, & McCarron, 2003). We selected 63 as a cut-off to ensure

Participants completed the PSWQ and the RRS again 24 hours before their laboratory visit to ensure they still met the above criteria for high worriers / high ruminators. The final sample consisted of *N* = 178 participants[6], with 62 in the CBM_ENH condition, 61 in CBM_RNT condition, and 55 in the CON condition. Conditions did not differ in regards to age (CBM_ENH: *M* = 30.01 years, *SD* = 11.80; CBM_RNT: *M* = 28.17, *SD* = 8.82; CON: *M* = 29.44, *SD* = 11.48; $F(2, 173) = 0.46$, $p = .631$) or gender (F/M ratio 48/14 in CBM_ENH, 54/7 in CBM_RNT and 44/11 in CON conditions; Pearson $\chi(2) = 2.79$, $p = .248$).

Measures

Standardized self-report questionnaires. Levels of trait worry were assessed using the PSWQ (Cronbach's α = .70 in the present sample). Additionally, trait rumination was measured using the RRS (Cronbach's α = .90). Depressive and anxiety symptoms were assessed using PHQ-9 (Cronbach's α =.79) and the GAD-7 (Cronbach's α = .79). The Spontaneous Use of Imagery Scale (SUIS; Reisberg, Pearson, & Kosslyn, 2003; Cronbach's α = .84) was included to measure participants' tendencies to use mental imagery in their everyday lives.

Interpretation bias measure: Recognition task. This task is based on Mathews & Mackintosh (2000) with materials (see Supplementary Materials for

that participants were experiencing high levels of depressive rumination.

[6] As the sample for the present study was drawn from a larger multi-session CBM study, the power analysis was conducted for multiple sessions of training. Based on Hirsch et al. (2018) and initial pilot work, our power calculation indicated that we would have 80% power to detect *d* = .5 with 53 participants per group (i.e., a total *N* = 159) at the 5% significance level. Anticipating drop out due to the multi-session nature of the study, we enrolled 178 participants. Although power was not calculated for the single session of training, we included participants who did not complete the full multi-session study and thus augmented the sample size.

example) used in Hirsch et al. (2018; in press). Each set included 20 scenarios (10 worry-related and 10 rumination-related) with descriptive titles. There were three sets of items[7], and the order of the sets was counterbalanced across participants before and after CBM-I / control session. Participants read ambiguous scenarios, completed word fragments of the final word, and answered comprehension questions. After they had read all the scenarios, four statements with a title of each scenario were randomly presented. Of the four statements, two targets were positive or negative resolutions of the ambiguity. Another two foil statements were unrelated positive or negative statements. These were used to make the task more oblique and reduce selection bias (see Hirsch et al., 2016, Supplementary Materials). Participants were asked to rate how similar each sentence was to the original scenario using a four-point Likert-type scale (1 - very different in meaning to 4 - very similar in meaning). A recognition test index of positive interpretation bias was computed for each participant by subtracting mean ratings for negative targets from mean ratings for positive targets. Thus, higher scores denoted greater similarity ratings to positive vs. negative targets (i.e., a more positive interpretation bias).

Imagery Training Exercise and Neutral Filler Task

Before the CBM-I scenarios, participants in the CBM_ENH condition completed a 10-15 minute imagery training exercise adapted from Holmes and Mathews (2005), and Holmes et al. (2006). Participants were introduced the concept of mental imagery first, then instructed to close their eyes and generate

[7] As stated, this study was part of a larger study with a further follow-up point not reported here. As such, there were three sets of items, rather than two.

a vivid mental image of a scene described by the experimenter. The training first involved imagining a lemon, followed by five example ambiguous scenarios with ambiguity resolved positively at the end. During the training, participants rated the vividness of their image from 1 (*not at all vivid*) to 5 (*extremely vivid*), and degree of positivity of the image from 1 (*not at all positive*) to 5 (*extremely positive*). Feedback was given to encourage participants to generate vivid, positive images. To control for the time spent on imagery training, participants in the CBM_RNT and CON conditions completed a neutral filler task, which involved a battery of questionnaires and a neutral attention task where they indicated the direction of target arrows (Basanovic, Notebaert, Grafton, Hirsch, & Clarke, 2017).

RNT Induction Phase and Neutral Grammar Task

Prior to the CBM-I (with or without enhanced imagery) participants in the CBM_ENH and CBM_RNT conditions engaged in an RNT induction phase. The RNT induction was used by Hirsch et al. (2018; in press), adapted from Hertel et al. (2014). Participants were asked to worry/ruminate about anything within the broad topic of social relationships for five minutes. They were asked to identify their worry/rumination topics first, then two questions were asked to facilitate their negative thoughts. Then participants typed their usual negative thoughts about this topic for three minutes and worried/ruminated about it for additional two minutes. This procedure was designed to activate interpretation bias and potentially render it more malleable to change. As we did not aim to change interpretation bias in the control condition, participants in the control condition completed a neutral grammar task to control for the durationof the RNT induction. This grammar task included reading neutral stories, making judgements on grammatical correctness, and answering basic comprehension questions.

Cognitive Bias Modification of Interpretation (CBM-I) and Active Control

CBM-I without imagery enhancement (CBM_RNT). This training session was identical to that used in Hirsch et al. (2018; in press). Participants listened to 50 scenarios that were emotionally ambiguous but eventually resolved in either a positive (76% of the time; 38 trials), or negative manner (12% i.e., 6 trials), or were left unresolved (12% i.e., 6 trials) by the ending of the scenario[8]. Participants were asked to imagine themselves in the scenarios. After each scenario, participants answered comprehension questions that required endorsement of a response in keeping with the interpretation provided in the scenario (i.e., a positive interpretation in positive trials and negative in negative trials; see Supplementary Materials for example). These questions enabled us to know whether participants had made a positive interpretation. Within the 38 positive trials, the mean positive interpretation rate was M = 0.92 (SD = 0.06). Participants received feedback on the accuracy of these answers, except for the trials in which ambiguity had not been resolved. To maximize the impact of training, participants were trained using worry or rumination related training materials depending on their dominant form of RNT as measured 24 hours prior to testing; that is those who scored ≥ 62 on the PSWQ completed training using worry materials, whereas those who scored ≥ 63 on RRS completed training

[8] Six negative trials were included to make sure that participants attended to the content of the scenarios (see Krahé et al., 2016). It is unlikely that the small number of negative trials had any impact on interpretation bias in this condition, and inclusion of negative trials during positive CBM-I training is common practice in the field.

using rumination materials. If participants scored above the cut-offs on both questionnaires, separate *z* scores for PSWQ and RRS were used, then materials were allocated based on the higher *z* score.

Imagery-enhanced CBM-I (CBM_ENH). Forty worry- or rumination-related scenarios (depending on their dominant form of RNT as described in the CBM_RNT condition section) used in Hirsch et al. (2018) were presented in the CBM_ENH condition. Twenty of them were resolved in a positive manner (identical to CBM_RNT) and twenty remained unresolved (see Supplementary Materials for example). For all the scenarios, participants were asked to imagine themselves in the scenarios as vividly as they could. For the unresolved trials, participants were asked to generate their own positive endings. Participants were instructed to create vivid images when they listened to the scenarios. Following the end of the scenario, they were asked to continue imagining the positive ending for 7 seconds. Furthermore, participants were again asked to answer comprehension questions after each trial as in the CBM_RNT condition above. The mean positive interpretation rate was *M* = 0.90 (*SD* = 0.09) for the 40 comprehensions questions. Thus, both the number of training trials and the fact that these were indeed positively resolved indicates that the training 'dose' was comparable between the two CBM-I conditions. Participants then rated either vividness or positivity of their mental images on visual analogue scales with the anchors 0 "*not at all*" to 100 "*extremely*" vivid/positive (i.e., "How positive was the outcome you imagined?"; "How vividly did you imagine the scenario described?"). Feedback was provided to encourage participants to generate vivid and positive images. The average ratings were *M* = 79.53 (*SD* = 12.87) for vividness and *M* = 74.46 (*SD* = 12.49) for positivity, indicating that participants were able to follow the instructions and produced vivid and positive mental images.

Active control (CON). Fifty ambiguous scenarios used in Hirsch et al. (2018; in press) were presented to participants (see Supplementary Materials for an example). All the scenarios remained unresolved (as in CBM_ENH unresolved trials) and were followed by a question. Half of the questions was related to a factual element in the scenarios, where accuracy feedback was provided. The other half of the questions was related to the ambiguity of the scenario, which was never followed by feedback, so allowing either interpretation without correction. The mean correct rate was *M* = 0.84 (*SD* = 0.09) for the 25 factual questions, and the mean positive interpretation rate was *M* = 0.46 (*SD* = 0.18) for the other 25 questions that were related to the ambiguity of the scenario.

Experimental Procedure

Twenty-four hours prior to the experimental session, participants completed questionnaires (PSWQ, RRS, PHQ-9, GAD-7, SUIS) online. During their visit[9], participants were randomly allocated to one of the three conditions: (1) CBM_RNT, (2) CBM_ENH or (3) CON. Then participants completed the recognition test. Following this, participants completed either the mental imagery training exercise (CBM_ENH condition) or a neutral filler task

[9]This is part of a larger study (Hirsch et al., in press), so there are additional descriptive questionnaires and tasks not reported here.

(CBM_RNT and CON conditions). They then completed the RNT induction (CBM_RNT and CBM_ENH conditions) or neutral grammar task (CON condition), followed by the interpretation training or control session (depending on condition), with a short break after half of the scenarios. Then participants completed the recognition test again.

Plan of Analysis

Participants with missing data on the recognition test (e.g., due to technical faults with the E-Prime program) and those with poor performance on the recognition test (scoring 2.5 standard deviations or more below the sample mean on the comprehension questions) were excluded from analyses. We examined whether conditions differed in terms of baseline measures of worry, rumination, anxiety, depression, and use of mental imagery. In the event of baseline differences, we controlled for the measure in the analysis. To examine the effect of condition on interpretation bias, we conducted a regression analysis with mean score on the post-training recognition test index as the outcome variable, condition (CBM_ENH, CBM_RNT, CON) as the predictor variable, and controlled for pre-training recognition test score. Wald tests were conducted to test simple and composite linear hypotheses about the parameters of the model. Sidak-corrected pairwise comparisons were used to follow-up the effect of condition.

Results

Twelve participants were excluded due to missing data (technical issues with E-Prime; n = 5) or poor performance on the recognition test (n = 7), leaving N = 166 for analyses. Descriptive statistics for baseline questionnaire measures are presented in Table 1. The three conditions did not differ in regards to pre-training interpretation bias, $F(2, 163) = 1.40$, $p = .250$. However, conditions differed in terms of baseline levels of worry on the PSWQ; therefore, we controlled for worry level in subsequent analyses.

Descriptive statistics for the recognition test are presented in Table 2. Condition significantly predicted post-training recognition test score (controlling for baseline recognition test score and level of worry using PSWQ), Wald test $F(2, 161) = 22.90$, $p < .001$, partial $\eta^2 = 0.22$. Sidak-corrected pairwise comparisons indicated that all conditions differed significantly from each other (CBM_ENH vs. CBM_RNT: $p = .010$; CBM_ENH vs. CON: $p < .001$; CBM_RNT vs. CON: $p < .001$). Post training, positive recognition test score was greatest (i.e., interpretations were most positive) in the CBM_ENH condition ($M = .94$, $SE = .09$), followed by the CBM_RNT condition ($M = .56$, $SE = .09$), followed by the CON condition ($M = .04$, $SE = .10$). Thus, the findings supported our hypotheses: interpretation training with enhanced imagery was more beneficial than interpretation training without enhanced imagery, and both training conditions promoted a more positive interpretive style relative to the matched control condition.

Discussion

Study 1 examined whether combining sustained imagery with positive interpretation training in a single session was more effective at promoting positive interpretations than interpretation training without such enhanced imagery. Consistent with our hypothesis, imagery-enhanced interpretation training was more effective in participants with high levels of RNT. Furthermore, as predicted, interpretation bias was more positive following both forms of interpretation training as compared to the active control condition.

It should be noted that the two interpretation training conditions differed from each other in several ways (e.g., regarding types and numbers of trials). However, we believe that the overall training dose was comparable between conditions (see footnote 8 and method for the positive interpretation rates for the two CBM-I conditions). The CBM_ENH but not the CBM_RNT condition contained explicit instructions to resolve ambiguous scenarios in a positive manner; while we cannot rule out that this may have contributed to the superior effect on interpretation bias post-training, the aim of the present study was to examine a more general question of whether enhancing interpretation training with imagery and self-generation facilitates greater change on interpretation bias than interpretation training without extended imagery and self-generation and to identify the most optimal type of CBM-I to carry forward to Study 2.

Furthermore, the two CBM-I conditions included an RNT induction, which we did not include in the control condition. While participants in the CBM-I conditions thus started the training with higher levels of RNT than did participants in the control condition, the fact that CBM-I conditions promoted a more positive interpretation bias relative to the control condition despite starting the training sessions with greater RNT speaks to the success of the training. Moreover, the aim of this study was to compare the two versions of CBM-I, and as both completed the RNT induction, this is unlikely to have influenced the results.

To assess change in interpretation bias after a single session of training, the present study employed the recognition test as a measure of interpretation bias. This is a robust and widely used assessment that has been used to measure interpretation bias in clinical populations (Eysenck et al. 1991) and change in interpretation bias after experimental manipulation (Mathews & Macintosh, 2000; Murphy, Hirsch, Mathews, Smith, & Clark, 2007), as well as across multiple sessions of interpretation training (Hirsch et al., 2018; in press). As highlighted by Hirsch et al. (2016), there are clear benefits to using this measure of interpretation bias. For example, the purpose of the task is opaque and thus avoids demand effects. The recognition test has two phases: phase 1 - reading the ambiguous scenarios, and phase 2 - rating the similarity of new statements (including interpretations) to the original. This means that an individual might only generate an interpretation when reflecting on the meaning of the ambiguous information, for example during phase 2, rather than when ambiguity is first encountered, or they may generate several different interpretations, and then select one (Hirsch et al., 2016). It is thus important to know whether interpretation bias training enhanced with imagery also facilitates positive interpretations made at the moment ambiguity is first encountered (known as 'online' processing).

Study 1 showed that imagery enhances the effectiveness of interpretation bias training in a sample of participants with high levels of RNT. Examining the effect of imagery-enhanced training on a measure of interpretation bias shows near transfer, that is, that the training affects the bias. The next step would be to show that this enhanced training also reduces negative intrusions associated with worry on a behavioral task (far transfer). Thus, in Study 2, we examined the effects of imagery-enhanced interpretation training (vs. an active control condition) on online and offline near-transfer measures of interpretation bias, as well as far transfer to negative thought intrusions associated with worry.

Study 2

The present study sought to examine whether imagery-enhanced interpretation training alters interpretations generated at the moment ambiguity is first encountered ('online', fast reflexive processing), or only at the offline stage in processing (a slower more reflective process where multiple interpretations could be generated and one option chosen). Whilst Study 1 demonstrated that offline bias change was augmented using imagery-enhanced training, impact on online interpretations has not been investigated. This has been highlighted by Hirsch et al. (2016) as a consistent limitation of the field. However, given that research to date in individuals with depression – who typically engage in high levels of rumination – shows no evidence of any online interpretation biases (Moser, Huppert, Foa, & Simons, 2012), one would not anticipate that training interpretations related to depressive rumination would alter interpretations at the online processing stage. Therefore, the present study examined online interpretation biases in relation worry only, rather than also in regard to rumination.

Online and Offline Markers of Interpretation Bias

The paucity of research into online interpretations of ambiguity in general and worry in particular has begun to be addressed. Feng et al. (2019) examined offline and online markers of interpretation bias in individuals with high or low levels of trait worry. Online interpretations were captured using a lexical decision task (LDT) in which real word targets matched either positive or negative resolutions to ambiguous scenarios. Feng et al. (2019) measured both reaction times and event-related potentials (ERP) as interpretation bias indices. The particular ERP they measured, the N400, is an excellent candidate marker of online interpretations as it can capture neural activity reflecting the resolution of ambiguity approximately 400ms after the target is presented (Moser et al., 2012). This provides information about interpretations at a temporally earlier point than that at which a behavioral (e.g., reaction time) response is generated. Larger negative N400 amplitudes are typically observed when encountering information that is difficult to integrate into the preceding context (e.g., when it is not expected). Thus, a larger N400 in response to positive versus negative targets would denote a more negative interpretation bias.

In line with previous research on socially anxious populations using the LDT to examine interpretation bias (Hirsch & Mathews, 1997; 2000), Feng et al. (2019) reported that low worriers displayed a positive interpretation bias, whereas high worriers demonstrated neither a positive nor negative bias, evidenced by both reaction time and N400 ERP interpretation bias indices. In contrast to the N400 findings in Feng et al. (2019), the earlier of Moser et al.'s studies (Moser, Hajcak, Huppert, Foa, & Simons, 2008) failed to find an N400 difference between high and low socially anxious groups in an interpretation assessment task, where ambiguous sentences were resolved in a negative or positive manner by the final grammatically correct words. Unlike Feng et al. (2019) or the current study, Moser et al. (2008) also looked at P600, a later ERP that has the potential to indicate whether expected interpretations are violated or not (i.e., expectation violation effect). They found a difference in interpretation bias, indicated by P600, between high and low socially anxious groups. However, in their later 2012 study, they only found a N400 but not a P600 difference between groups. They argued that the reason for the discrepancy between studies is that N400 is likely to be more sensitive with more personally relevant material that activates effortful processing of its meaning. Therefore, the higher relevance of materials for participants in their 2012 study led to a stronger N400 effect. Given that the materials we used were developed in a focus group with high worriers and were thus designed to be highly relevant to high worriers, we felt that it was appropriate to use N400 as an ERP index of interpretation.

Although Feng et al. (2019) suggest key differences in online interpretation bias between high and low worriers, the question remains as to whether interpretation bias training affects online interpretation bias indicated by both reaction time and N400 ERP indices. We investigated this question using imagery-enhanced interpretation training, given its superiority over non-imagery-enhanced interpretation training in Study 1.

Study 2 thus evaluated the impact of imagery-enhanced interpretation training on offline, online and neurophysiological (ERP) indices of interpretation bias. It also investigated whether imagery-enhanced interpretation training impacted on a far-transfer measure of negative intrusions associated with worry. We hypothesized that individuals who received imagery-enhanced interpretation training (as compared to an active control condition) would show a more positive interpretation bias at the online stage (as measured by reaction time and ERP on the LDT) and at the offline stage (as measured by the recognition test), and would report fewer negative intrusions on a worry task.

Method

Design

The second study investigated the effect of imagery-enhanced CBM-I by measuring interpretation indexed using online reaction times and ERP, offline recognition test rating, and levels of worry indexed by the number of negative intrusions, after the imagery-enhanced CBM-I (CBM_ENH) or the active control condition (CON) in a high worry population. High worriers were randomly allocated to the CBM_ENH condition or CON conditions. Self-report questionnaires were administered to assess the extent of worry and mood at baseline. We measured offline interpretation biases prior to and after CBM_ENH/ CON via the recognition task. Online interpretation biases were measured after the training or control session using reaction time and ERP indices in the LDT. We also assessed levels of worry using the breathing focus task post CBM_ENH/CON. The study was approved by the King's College London Research Ethics Committee.

Participants

Participants with high levels of worry were recruited from university circular emails and online advertisements and provided informed consent. Participants who scored 56 or more on the PSWQ[10], aged between 18 to 65, fluent in English, with normal or correct-to-normal vision and hearing, and who didn't have a seizure disorder or current brain injury, were recruited to this

[10] Given the broader focus on high worriers without the criteria of mood in the clinical range, we used a lower cut-off of PSWQ in Study 2. The cut-off score was 56 or more to identify high worriers because this score is one deviation below the mean of diagnosed GAD (Molina, & Borkovec, 1994), and is commonly used in high worry research.

study. Participants completed the PSWQ again 24 hours before the lab session to ensure participants still met the criterion for high worriers. The sample comprised *N* = 66: *n* = 35 participants in CBM_ENH condition and *n* = 31 participants in the CON condition completed the session[11]. Conditions did not differ significantly regarding age, gender, and self-reported worry levels. Participant demographic characteristics are presented in Table 3.

Measures

Standardized self-report questionnaires. As in Study 1, levels of trait worry were assessed using the PSWQ (Cronbach's α = .74 in the present sample). Depressive and anxiety symptoms were assessed using PHQ-9 (Cronbach's α =.86) and the GAD-7 (Cronbach's α = .82).

Interpretation bias measures.

Recognition task. The task was the same as that used in Study 1 except that only a subset of 10 worry-related items that were presented in Study 1 were used per set. There were two sets of items, and the order of the sets was counterbalanced across participants before and after CBM-I.

Lexical decision task (LDT). This task is based on Hirsch and Mathews (1997; 2000) and adapted by Feng et al. (2019). Participants were asked to read 90 ambiguous worry-related sentences with 60 active word trials resolving ambiguity in positive (30) or negative (30) ways on the final word of the

[11] The sample size is based on power 0.8 and alpha 0.05, using effect sizes from the breathing focus task in post-test assessment phase in the CBM-I studies (Hayes et al., 2010; Hirsch et al., 2009), which indicated 26 participants per condition. We decided to test 35 participants per condition because we had included novel tasks (the recognition task and LDT) and an ERP measure, and we wanted to make sure we had enough power on these novel outcome indices.

sentence[12], which was presented as a lexical decision (e.g., "You receive a letter from the university you applied to, it says that you have been ___."), where participants indicated if the letter string presented at the end was a real word or not as quickly and accurately as possible. One third of trials were followed by comprehension questions to ensure participants read sentences carefully. Four sets of materials were counterbalanced across participants. The benign and negative target words were matched for word frequency.

The median[13] reaction times for positive or negative trial words were computed as interpretation bias indices. A positive interpretation bias index for reaction time was computed by subtracting the positive trials reaction time median from negative trials reaction time median. Thus, a higher score indicated a greater positive interpretation bias.

The N400 amplitudes[14] for positive and negative trials were also computed as an interpretation bias index. A larger negative N400 amplitude following presentation of the words indicated that the words were not consistent with participants' expectations. The positive interpretation bias index for N400 was computed by subtracting the negative trials N400 mean amplitude for

[12] There were four sets of materials counterbalanced across participants. Within the four sets, one set of materials had significantly different distributions between target words in negative trials and in benign trials (Kruskal-Wallis Test, p = .008), with a higher frequency for negative target words. Given that the sets were counterbalanced across participants, it is unlikely to account for any findings.

[13] The reaction time medians were used in this study, in keeping with Feng et al (2018) because reaction time data are positively skewed and medians are more insensitive than means to the skew of distributions (Baayen & Milin, 2010).

[14] See Supplementary Materials for detail of Electroencephalography (EEG) recording and processing for the LDT.

negative trials from N400 mean amplitude for positive trials. A higher value indicated a more positive interpretation bias.

Behavioral measure of worry: Breathing focus task. The breathing focus task (Eagleson, Hayes, Mathews, Perman, & Hirsch, 2016) is a behavioral measure of worry. Participants were asked to focus on their breathing for five minutes. During this period, 12 signals at random intervals prompted participants to indicate whether they were focusing on their breathing or had thought intrusions that were positive, negative or neutral. The number of negative intrusions reported during the breathing focus period was the outcome measure of worry and ranged from 0 to 12.

Imagery Practice Exercise and Neutral Filler Task

The imagery practice exercise was completed by the CBM_ENH participants. The procedure was the same as that used in the Study 1 except that it was a computerized task. A neutral filler task was completed by the CON condition that involved watching a neutral video and answering questions about it before completing a neutral questionnaire about general eating habits (British Heart Foundation, 2012).

Worry Induction

A worry induction was completed by both CBM_ENH and CON participants which was identical to Study 1 except they could select a personal worry from one of five worry domains.

Cognitive Bias Modification for Interpretation (CBM-I) and Active Control

The CBM_ENH and CON conditions were identical to Study 1. Participants in the CBM_ENH condition rated either vividness or positivity of their mental images from 1 “*not at all”* to 9 “*extremely”* after each scenario. The average rating in CBM_ENH condition for vividness was M = 7.49 (SD = 0.83) and M = 7.08 (SD = 0.94) for positivity. They were again asked to answer comprehension questions after each trial. The mean positive interpretation rate was M = 0.87 (SD = 0.10) for the 40 comprehensions questions. Participants in the control condition answered 25 factual questions and 25 questions that were related to the ambiguity of the scenario. The mean correct rate was M = 0.90 (SD = 0.22) for the 25 factual questions, and the mean positive interpretation rate was M = 0.37 (SD = 0.22) for the other 25 questions related to the ambiguity of the scenario.

Experimental Procedure

Participants completed questionnaires (PSWQ, PHQ-9, and GAD-7) online within 24 hours prior to the testing session. Participants were randomized to the CBM_ENH or CON condition. They gave informed consent and the electroencephalography (EEG) cap was fitted. Then they completed the recognition task, followed by the imagery training exercise (CBM_ENH) or neutral filler task (CON), followed by worry induction, and CBM_ENH or CON sessions (depending on condition). Participants then completed the recognition task again. A booster set of CBM_ENH/ control scenarios (16 scenarios for CBM_ENH; 20 scenarios for CON to match for time) was then completed prior to the lexical decision task[15], followed by breathing focus task.

Plan of analysis

[15] The lexical decision task was not administered pre training due to time constraints.

To examine the training effect on interpretation bias assessed by the recognition test, as in Study 1, regression analysis was conducted for the recognition task with the positive bias scores (positive target scores minus negative target scores) in the post CBM_ENH/CON session test as the outcome variable. Condition (CBM_ENH vs. CON) served as the predictor variable and we controlled for positive bias scores at pre-test. For the LDT, a regression analysis was conducted with the reaction time positive bias index (negative trials' reaction time median minus positive trials' reaction time median) as the outcome variable, and condition (CBM_ENH vs. CON) as the predictor variable. Similarly, the ERP positive bias index (positive trials mean amplitude minus negative trials mean amplitude) served as the outcome variable in the regression analysis, and condition (CBM_ENH vs. CON) as the predictor variable.

To examine the training effect on worry levels indicated by the negative intrusions in the breathing focus task, regression analysis was conducted with the number of negative intrusions as the outcome variable, and condition (CBM_ENH vs. CON) as the predictor variable. In the event of non-normally distributed data, we conducted regression analysis with bootstrapping (1000 replications).

Results

Effects of Imagery-Enhanced Interpretation Training vs. Active Control

Offline interpretation bias. On the recognition task, one participant was excluded due to poor task performance (scoring < 2.5 *SD* below the mean for accuracy on the recognition task comprehension questions), leaving 35 participants in the CBM_ENH condition and 30 participants in the CON condition for the following analyses. In order to determine whether the conditions differed in their interpretation bias before the interpretation training /active control condition, a t-test was conducted for the pre-test positive bias scores. We found that the two conditions did not differ in their positive bias scores at pre-test, $t(63) = 1.07$, $p = .288$. In the regression analysis, condition (CBM_ENH vs. CON) was significantly associated with positive bias scores at post-test (β= -0.48, p<.001, Hedges' g = 1.11; see Table 4 for descriptive statistics and results of the statistical analyses). As predicted, interpretation bias post training was more positive in the CBM_ENH condition compared to the CON condition.

Online interpretation bias.

Behavioral index. In the lexical decision task, three participants were excluded due to poor task performance (scoring < 2.5 *SD* below the mean for accuracy on the lexical decision task comprehension questions or lexical judgements), leaving 33 participants in the CBM_ENH condition and 30 participants in the CON condition for the regression analysis. As expected, condition (CBM_ENH vs. CON) was significantly associated with positive bias scores (β= -0.29, p=.020, Hedges' g = 0.60; see Table 4 for descriptives and analyses results). In line with our prediction, a more positive interpretation bias was found in the CBM_ENH condition compared to the CON condition.

ERP index. In the lexical decision task, five additional participants were excluded due to technical problems with the EEG recording and electrical noise[16], leaving 28 participants in the CBM_ENH condition and 30 participants in

[16] One person was excluded due to recording failure. Another four noisy data were also excluded. The average of accepted trials was 87.07% in CBM_ENH and 87.80% in the CON condition.

the CON condition for the regression analysis. In contrast with our prediction, no significant association was found between condition and positive bias index (*β*= 0.04, *p*=.776, Hedges' *g* = -0.07; see Table 4)[17].

Worry levels after imagery-enhanced interpretation training vs. active control. We examined whether level of worry (negative intrusions) differed between conditions (CBM_ENH vs. CON) by a regression analysis with bootstrapping (1000 replications) given that the data was non-normally distributed. As expected, condition was significantly associated with number of negative intrusions. Participants in the CBM_ENH condition reported fewer negative intrusions compared to the control condition following completion of the CBM_ENH/CON session (*β*= 0.27, *p*=.028, Hedges' *g* = -0.55; see Table 4 for descriptives and model results).

In sum, behavioral findings on both measures of interpretation bias indicated that CBM_ENH led to a more positive interpretation bias than the control condition. The finding in the breathing focus task also showed that CBM_ENH led to a reduction in worry. However, we did not detect a difference between conditions on the ERP interpretation bias index.

Conditions did not differ in the accepted trial numbers (t (56) = -1.28, p = .207).

[17] In keeping with Feng et al., (2018), three-way (2 x 2 x 6) ANOVA was conducted for 6 centro-parietal electrode sites (C3, Cz, C4, P3, Pz, and P4) with Condition (CBM_ENH vs. CON) as a between-group variable and Valence (benign vs. negative) and Electrode Site as within-group variables. There was a significant main effect of Electrode sites (F (5, 280) = 58.94, p < .001, η^2_p= .51). However, consistent with the regression analysis, no other significant results were found (Condition: F (1, 56) = 0.08, p = .771, η^2_p< .01; Valence: F (1, 56) = 3.23, p = .078, η^2_p= .06; Condition x Valence: F (1, 56) = 0.17, p = .682, η^2_p< .01; Condition x Electrode: F (5, 280) = 1.41, p = .222, η^2_p= .03; Valence x Electrode sites: F (5, 280) = 0.86, p = .508, η^2_p= .05; Condition x Valence x Electrode sites: F (5, 280) = 0.65 , p = .658, η^2_p= .01)

Discussion

Study 2 examined the effects of imagery-enhanced interpretation training on online and offline assessments of interpretation bias, and on a far-transfer worry task. Replicating Study 1, and supporting our hypothesis, the offline interpretation bias measure showed a greater positive interpretation bias in the imagery-enhanced interpretation training condition after training, compared to the active control. Also, in keeping with our hypothesis, greater positive bias was observed in the training condition on the lexical decision task online assessment (as indexed by reaction time), compared to the control condition. Interestingly, imagery-enhanced training effects were not observed at a neurophysiological level; ERPs showed no effect of training vs. control. Despite this, fostering reflective positive interpretations is potentially beneficial to high worriers, since on a far-transfer task (breathing focus task), those in the training condition reported significantly fewer negative intrusions compared to the control participants.

Imagery-enhanced interpretation training encompassed self-generation of positive outcomes on half the training trials, and required participants to imagine these personally generated positive outcomes. This self-generation may have augmented imagery effects due to greater personal saliency and potential engagement of the imagery's idiosyncratic nature. Arguably, one might expect that active requirement to generate positive outcomes and then imagine them would facilitate positive offline interpretations that could occur as a result of effortful processing. However, the effects were also evident for online interpretations generated when ambiguity was first encountered, as indexed by reaction times. It may be that generating positive interpretations becomes more spontaneous over the training session, enabling training to impact on online interpretations indexed by behavioral responses. Future research could determine whether augmented training effects observed for offline interpretations in Study 1 also applies to online interpretations. This could be achieved by comparing performance on behavioural indices of online tasks across imagery-enhanced and non-imagery-enhanced interpretation training.

In contrast to the reaction time data on the online lexical decision task, there were no observed effects of training on ERP measures. Given that Feng et al. (2019) demonstrated that this task is sensitive to low trait worriers' positive interpretation bias (and in keeping with Moser et al., 2012, for social anxiety), why did we not observe this effect in high worriers trained to generate positive interpretations? One possible answer, based on earlier work, is that N400 reflects how easy it is to integrate information into a given context based on an individual's semantic memory (Kutas & Federmeier, 2000; Swaab, Ledoux, Camblin, & Boudewyn, 2012). Hence, information that is discordant with semantic memory, which would be harder to integrate, will be more likely to violate one's expectations and produce a larger N400 amplitude. However, a relatively brief single session of interpretation training may not be sufficient to alter early-stage habitual interpretive processes that are indexed by N400. Future research could investigate this using more training trials (perhaps presented over multiple training sessions) to determine whether imagery-enhanced interpretation training alters ERP response.

Another possibility is that the nature of the positive interpretation bias facilitated by training may fundamentally differ from that of low trait worriers, thus explaining the lack of ERP effects in the current study and in the contrast to data reported by Feng et al. (2019). Given that the current study is the first to assess interpretation bias after training using ERPs, future research could employ multi-session training, which leads to reductions in trait worry (e.g. Hirsch et al., in press), and interpretation bias could then be assessed at follow-up using ERP techniques.

General Discussion

The present findings are in line with other studies that highlight the utility of imagery-enhanced interpretation bias training (e.g., Lang, Blackwell, Harmer, Davison, & Holmes 2012; Holmes et al., 2006; Holmes, Lang & Shah, 2009; Pictet, Jermann, & Ceschi, 2016). Our first study focused on interpretation training in relation to RNT in general. We demonstrated that either form of interpretation training with prior RNT led to more positive interpretations than a control condition. Furthermore, positive interpretation training that was enhanced by self-generation of outcomes and imagining oneself in a positively disambiguated situation was more effective than unenhanced interpretation training in reducing negative interpretation bias. In the second study, we focused specifically on high worriers, and found that, compared to an active control condition, enhanced interpretation training reduced both offline negative interpretation bias (as indexed by the recognition task) and online negative interpretation bias (as indexed by the LDT). It also led to a reduction in negative intrusions on a far-transfer behavioural measure of worry. Hence, our two studies demonstrated the beneficial effects of imagery-enhanced interpretation training in relation to RNT, and worry in particular.

Having imagery in mind, instead of verbal processing, has been found to interact with interpretation bias. In work on social anxiety, it is the presence of negative imagery (rather than a lack of imagery per se) that interacts with negative interpretations (Hertel, Brozovich, Joormann, & Gotlib 2008, Study 2; Hirsch, Clark, Mathews, & Williams, 2003; Hirsch, Mathews, & Clark, 2007). This work supports the combined cognitive bias hypothesis (Hirsch et al., 2006), that posits that imagery and interpretation biases can combine to maintain psychopathology. In relation to the nature of RNT, and worry in particular, we were interested in whether generating positive imagery and self-generation can facilitate greater positive interpretation bias.

One mechanism through which imagery may augment interpretation training effects is its ability to evoke emotional responses, such that imagining the situation seems more akin to being in the situation (e.g. Holmes et al. 2006; Mathews, Ridgeway, & Holmes, 2013). Indeed, mental imagery has been found to be more emotionally arousing and more likely to be confused with real events than verbal processing (Mathews et al. 2013). Holmes and colleagues (Holmes, Lang, & Deeprose, 2009; Holmes & Mathews, 2005) propose that imagery corresponds to sensory experience and in this sense can provoke an emotional response akin to that of an event that has happened in real life. Being exposed to positive interpretations of ambiguous scenarios in this potentially more realistic way via imagery may thus facilitate a greater shift in bias in a positive direction. Renner, Murphy, Ji, Manly, and Holmes (2019) argue that mental imagery is a 'motivational amplifier'. In this sense, positive imagery allows individuals to experience pleasant events that have not yet occurred. It is argued that this can potentially increase motivation and engagement with activities. If so, imagery might motivate individuals with RNT to engage more with positive outcomes during training. However, Study 1 did not find any differences between the three conditions regarding mood ratings obtained immediately after interpretation training/ the active control condition (see Supplementary Materials). Therefore, positive mood is less likely to be the mechanism underlying the augmentation of training effects that result from imagery-enhanced interpretation training.

A second route through which the imagery-based interpretation condition may have enhanced training effects is by facilitating a more concrete rather than abstract thinking style. The quasi-verbal processing mode that characterizes worry and other forms of RNT is proposed to perpetuate more abstract (vs. concrete) thoughts. Conversely, thinking about worries in imagery form (which is inherently more concrete) appears to attenuate worry. For example, asking individuals with high levels of worry to worry in imagery form leads to fewer negative thought intrusions, compared to verbal worry (Stokes & Hirsch, 2010; Hirsch et al., 2015). Encouraging the use of mental imagery may thus have increased the level of concreteness used to think about the positive interpretations, especially for self-generated outcomes.

Third, participants undergoing imagery-enhanced interpretation training were asked to imagine themselves in all the training scenarios and for fifty percent of these scenarios they were required to generate their own positive endings. Thus, they received explicit instructions to resolve scenarios in a positive manner. Creating an idiosyncratic outcome may have served to enhance the salience of the training via more personally-relevant situations being represented in imagery. However, Rohrbacher, Blackwell, Holmes, and Reinecke (2014) used a non-selected population to compare imagery–enhanced interpretation bias training with active generation of outcomes, to imagery–enhanced interpretation bias training without active generation. Rohrbacher et al. (2014) found no evidence to support the idea that encompassing active generation produced superior training effects; both conditions were equally effective at facilitating positive interpretations compared to a control condition. In the work presented here, Study 1 compared interpretation training with neither sustained imagery nor self-generation to enhanced interpretation training with imagery and self-generation. Given this, we are unable to determine which component (imagery or self-generation of outcomes) or their combination augmented our training effects. One may however suppose that in keeping with earlier work (Lang et al., 2012; Hirsch et al., in press; Holmes et al., 2006; Holmes, Lang & Shah, 2009; Pictet et al., 2016), sustained positive imagery was beneficial. Furthermore, given our population had high levels of repetitive negative thinking (worry and/or rumination) practice in self-generation of positive outcomes may be particularly helpful due to their low trait levels of positive interpretations (Krahé et al., 2019). Supporting this point, Hirsch et al. (in press) reported the longer-term impact of Study 1 training within a multi-session context and found that the imagery-enhanced interpretation bias training (which includes self-generation) was more effective than interpretation training without imagery enhancement at reducing trait RNT.

The overall findings in Study 1 revealed that imagery-enhanced interpretation training led to more positive offline interpretations compared to interpretation training with RNT, or an active control condition. Furthermore, Study 2 revealed that imagery-enhanced interpretation training was more effective in promoting offline interpretation bias and in reducing worry than the active control condition. As mentioned above, the effectiveness of imagery-enhanced interpretation training may be due to the self-generation on of interpretations or the generation of prolonged (7 seconds) imagery of the positive interpretation, or both. Future research could investigate whether both enhancements are required to see the greater impact on interpretation bias, or whether self-generation or positive outcome imagery are sufficient in their own right.

Furthermore, Study 2 showed imagery-enhanced interpretation training increased positive interpretations in offline and online behavioural indices compared with the control condition. However, we did not find an N400 evidence of online interpretations changing. This may be due to the brief (40 trials) single-session training design that may be insufficient to modify responses at a neural level. Future research could investigate under what conditions interpretation training enables high trait worriers to develop a positive interpretation bias that operates at very early stages of processing (e.g., as captured by the N400), as found in low trait worriers. It is possible that the training elements have to be more relevant to online information processing to induce a change, such as more automatic responses or a short time between ambiguity and interpretation. The other possibility is that the change would occur when there is a greater dose of training in a single session (e.g., 100 trials). Alternatively, N400 effects may emerge after a multi-session interpretation training. It would also be interesting to investigate the extent of training needed to modify the early stages of interpretation generation as evidenced by N400, and whether this modification of early interpretative stage leads to more beneficial outcomes (e.g., worry reduction).

One limitation of the materials we used for the LDT is that target word frequencies were not fully matched. This was due to the nature of the material, since the ambiguous sentences need to be interpreted in both benign and negative ways, and the target words have to be in keeping with one of these interpretations. This greatly reduced the options in selecting the target words and made it difficult to match benign and negative targets on lexico-semantic characteristics. Given that the material sets were counterbalanced within conditions, both conditions were equally exposed to a given negative or benign target, thus it is unlikely that condition differences are attributable to the differences in word frequencies. Nevertheless, future research could attempt to ensure word characteristics are fully balanced across materials when matching the target words to the most appropriate interpretations. Further, we did not pre-register the studies and acknowledge that doing so could have strengthened the studies reported.

In summary, this research used a single-session experimental design to investigate whether imagery-enhanced interpretation training promotes a more positive interpretation bias. Study 1 demonstrated that engaging with positive imagery interacts with interpretation training to enhance the effects of interpretation bias training, and Study 2 showed that this enhanced training influences both online and offline interpretations, as well as reducing negative thought intrusions. Certainly, the present research suggests that there are benefits to engaging in sustained imagery in the context of interpretation bias training. We show that imagery interacts in favourable ways with other cognitive processes that are key to the maintenance of pathological worry to reduce negative thought intrusions associated with worry.

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Table 1.

Means (standard deviation) and statistics for questionnaires in Study 1.

	CBM_ENH *n* = 59	CBM_RNT *n* = 55	CON *n* =52	Difference test (ANOVA with Sidak-corrected pairwise comparisons)
PSWQ	67.46 (6.51)	69.60 (5.3)	70.48 (5.00)	F (2, 163) = 4.23, p = .016; ENH vs. STD: p = .191, ENH vs. CON: p = .003, STD vs. CON: p = .296
RRS	59.78 (12.27)	56.02 (13.47)	59.31 (10.86)	F (2, 163) = 1.55, p = .215
PHQ-9	12.66 (4.88)	11.80 (5.54)	12.25 (4.65)	F (2, 163) = 0.42, p = .661
GAD-7	12.63 (3.87)	13.05 (4.03)	13.17 (4.16)	F (2, 163) = 0.29, p = .750
SUIS	40.76 (9.76)	41.05 (9.82)	41.19 (9.28)	F (2, 163) = 0.03, p = .971

Notes. *CBM_ENH= imagery-enhanced interpretation training condition; CBM_RNT = interpretation training condition without imagery enhancement; CON= active control condition; PSWQ = Penn State Worry Questionnaire; RRS = Ruminative Response Scale; PHQ-9 = Patient Health Questionnaire; GAD-7 = Generalized Anxiety Disorder 7-item scale; SUIS = Spontaneous Use of Imagery Scale.*

Table 2.

Means and standard deviation for the recognition test in Study 1.

	Pre-test		Post-test	
	Mean	*SD*	Mean	*SD*
CBM_ENH	0.11	0.69	0.97	0.75
CBM_RNT	0.03	0.79	0.57	0.81
CON	-0.11	0.63	0.00	0.70

Notes. *CBM_ENH= imagery-enhanced interpretation training condition; CBM_RNT = interpretation training condition without imagery enhancement; CON= active control condition.*

Table. 3

Means (standard deviation) and statistics for age, gender and questionnaires in Study 2.

	CBM_ENH n = 35	CON n = 31	Test
Age	27.77(8.21)	26.35(7.53)	t (64) = 0.73, p = .470
Female (%)	86%	87%	$\chi^2(1)$ = 0.03, p =.870
Questionnaires:			
PSWQ	67.49 (5.85)	67.39 (5.95)	t (64) = 0.07, p = .946
GAD-7	11.43 (5.04)	10.26 (3.38)	t (64) = 1.09, p = .278
PHQ-9	11.20 (6.15)	9.81 (6.07)	t (64) = 0.92, p = .359

Notes. *CBM_ENH= imagery-enhanced interpretation training condition; CON= active control condition; PSWQ = Penn State Worry Questionnaire; GAD-7 = Generalized Anxiety Disorder 7-item scale; PHQ-9 = Patient Health Questionnaire*.

Table 4.

Descriptive statistics and analyses results for imagery-enhanced interpretation training vs. control condition for interpretation bias and worry levels.

		CBM_ENH			CON			Analyses results						
	Time point	*n*	Mean	*SD*	*n*	Mean	*SD*	*B*	*SE*	*β*	*p* value	95% CI lower	95% CI higher	Hedges' *g*
Recognition Test	Pre-test	35	-0.03	0.70	30	-0.23	0.80							
	Post-test	35	0.63	0.73	30	-0.24	0.83	-0.87	0.19	-0.49	<.001	-1.26	-0.48	1.11
Lexical Decision Task Reaction time	Post-test	33	72.79	71.21	30	27.03	80.81	-45.76	19.15	-0.29	.020	-84.06	-7.45	0.60
Lexical Decision Task ERP	Post-test	28	0.70	2.66	30	0.94	3.61	0.24	0.84	0.04	.776	-1.44	1.92	-0.07
Breathing Focus Task Negative Intrusions	Post-test	35	1.06	1.11	31	1.81	1.58	0.75	0.33	0.27	.028	0.08	1.42	-0.55

Notes. *CBM_ENH= imagery-enhanced interpretation training condition; CON= active control condition; ERP=event related potential, N400 amplitudes for interpretation bias index was presented in the table.*