

The worrying mind in control: An investigation of adaptive working memory training and  
cognitive bias modification in worry-prone individuals

Maud Grol<sup>a</sup>, Anne K Schwenzfeier<sup>b</sup>, Johannes Stricker<sup>a</sup>, Charlotte Booth<sup>a</sup>, Alexander  
Temple-McCune<sup>a</sup>, Nazanin Derakshan<sup>c</sup>, Colette Hirsch<sup>d</sup>, Eni Becker<sup>b</sup>, and Elaine Fox<sup>a</sup>

<sup>a</sup> Department of Experimental Psychology, University of Oxford, UK

<sup>b</sup> Behavioural Science Institute, Radboud University, the Netherlands

<sup>c</sup> Department of Psychological Sciences, Birkbeck University of London, UK

<sup>d</sup> King's College London, Institute of Psychiatry, Psychology and Neuroscience, UK

Author Note

Correspondence concerning this article should be addressed to Maud Grol,  
e-mail: [Maud.Grol@psy.ox.ac.uk](mailto:Maud.Grol@psy.ox.ac.uk). Department of Experimental Psychology, University of  
Oxford, New Richards Building, Old Road Campus, Oxford OX3 7LG

### Abstract

Worry refers to the experience of uncontrollable negative thoughts. Cognitive models suggest that the combination of negative information processing biases along with diminished attentional control contribute to worry. In the current study we investigate whether promoting a) adaptive interpretation bias and b) efficient deployment of attentional control would influence the tendency to worry. Worry-prone individuals ( $n = 60$ ) received either active cognitive bias modification for interpretation bias (CBM-I) combined with sham working memory training (WMT), adaptive WMT combined with sham CBM-I, or sham WMT combined with sham CBM-I. Neither of the active training conditions reduced worry during a breathing focus task relative to the control condition. However, when considering inter-individual differences in training-related improvements, we observed a relation between increases in positive interpretation bias and a decrease in negative intrusions. Moreover, increases in working memory performance were related to a reduction in reactivity of negative intrusions to a worry period. Our findings show that facilitating a more benign interpretation bias and improving working memory capacity can have beneficial effects in terms of worry, but also highlight that transfer related gains from existing training procedures can be dependent upon improvement levels on the training task.

Keywords: working memory training; cognitive bias modification; interpretation bias; attentional control; anxiety; worry

Worry is a form of repetitive thinking involving negative thoughts, typically about future events with uncertain or ambiguous outcomes, and is a hallmark cognitive characteristic of anxiety (Borkovec, Robinson, Pruzinsky, & DePree, 1983; Sibrava & Borkovec, 2006). Excessive worry about several topics is a prerequisite for a diagnosis of generalized anxiety disorder (GAD), while in other anxiety disorders worry is more focused on specific issues, e.g. worry about having a panic attack in panic disorder (American Psychiatric Association, 2013). Integrating basic research on the causal mechanisms underlying the tendency to worry is an important step towards exploring more sophisticated interventions targeting worry and anxiety.

Cognitive models of anxiety and worry have proposed that both automatic biases in the processing of emotional information and impairments in the control of attention can contribute to the cause and maintenance of pathological worry (Berggren & Derakshan, 2013; Hirsch & Mathews, 2012; Hirsch, Meeten, Krah, & Reeder, 2016). A tendency to interpret ambiguous information in a more negative or threatening manner has been related to anxiety and worry (e.g. Eysenck, Mogg, May, Richards, & Mathews, 1991; Mathews & MacLeod, 2005; for a recent review see, Hirsch et al., 2016). A number of methods have been developed that aim to modify this bias in interpretation - cognitive bias modification for interpretation (CBM-I) - which allows investigation of whether these biases have a causal effect on anxiety and worry. Grey and Mathews (2000), and Mathews and Mackintosh (2000) were the first to show that it is possible to modify interpretative bias in healthy individuals and that this can evoke changes in state anxiety according to the induced (positive or negative) interpretative bias.

A recent meta-analysis on the effectiveness of CBM-I (Menne-Lothmann et al., 2014) found that benign interpretation training had a large effect on post-training endorsement of positive versus negative interpretations. A small to medium effect was found for the change

in interpretation bias across training, but this effect was increased by the use of feedback during training, use of imagery, and the number of training sessions. Benign interpretation training was the only condition to show a significant change in positive interpretation bias; however, this training effect (i.e. the degree of change in bias) was only significantly different from the change in bias caused by negative training but not as compared to control training (Menne-Lothmann et al., 2014). Furthermore, both benign and control training resulted in a small but significant reduction in negative mood.

Previous studies in worry-prone individuals (Hirsch, Hayes, & Mathews, 2009) and GAD patients (Hayes, Hirsch, Krebs, & Mathews, 2010) used a single-session interpretation bias training consisting of a combination of a homograph training task (Grey & Mathews, 2000) and an ambiguous scenario task. Auditory scenarios of emotionally ambiguous events were played to individuals. The scenario remained ambiguous up to the final word, which determined whether the scenario was either threatening or benign. A comprehension question was then presented to individuals for which the correct answer confirmed the provided outcome of the scenario (Hirsch et al., 2009). Feedback was used to reinforce the intended interpretation of the scenario. For the positive interpretation training condition, the scenarios were always resolved in a benign manner, while for the control training condition, the scenarios were resolved in a threatening manner half of the time and in a benign manner the other half. Individuals who received positive interpretation training, as compared to control training, reported fewer negative intrusive thoughts after training and experienced less anxiety during a task designed to assess the tendency to worry (Hayes, Hirsch, Krebs, & Mathews, 2010; Hirsch et al., 2009).

Besides biases in the processing of emotional information, impairments in the control of attention are also believed to contribute to the cause and maintenance of worry (Berggren & Derakshan, 2013). Broadly speaking, attentional functions can be categorized into two

systems, one subsystem that is involved in goal-directed, top-down selection, and a more stimulus-driven, bottom-up subsystem (Corbetta & Shulman, 2002). The Attentional Control Theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007, p. 339) postulates that worry and anxiety “decreases the influence of the goal-directed attentional system and increases the influence of the stimulus-driven attentional system.” Research shows that working memory capacity and other executive function tasks share an underlying component of executive attention (McCabe, Roediger III, McDaniel, Balota, & Hambrick, 2010) and recent work demonstrates a strong link between attentional control and working memory (Shipstead, Lindsey, Marshall, & Engle, 2014). The efficiency of central executive functions of shifting between mental sets, updating and monitoring working memory content, and inhibition of irrelevant information (Miyake et al., 2000) are impaired by anxiety and worry, thus reducing attentional control (Berggren & Derakshan, 2013).

Several studies have shown that worry-prone individuals show processing efficiency related impairments on behavioural as well as neural measures requiring the efficient exercise of attentional control (Owens, Derakshan, & Richards, 2015; Sari, Koster, & Derakshan, 2016). Individual differences in propensity to worry have also been shown to impair the ability to inhibit irrelevant distractors (Fox, Dutton, Yates, Georgiou, & Mouchlianitis, 2015) and to inhibit threat-related distractors in an emotional version of a change detection working memory task (Stout, Shackman, Johnson, & Larson, 2015). A recent meta-analysis confirms there is a moderate and reliable association between anxiety and poorer performance on measures of working memory capacity (Moran, 2016). The development of cognitive training tasks has allowed investigators to further study the effects of facilitating working memory capacity. Working memory training has received a lot of attention but it remains a controversial topic. Several meta-analyses report mixed findings with some concluding working memory training does have benefits for cognitive skills and academic performance

(Au et al., 2015) while others conclude working memory training does not improve performance (Melby-Lervåg, Redick, & Hulme, 2016). A recent systematic review (Koster, Hoorelbeke, Onraedt, Owens, & Derakshan, 2017) examining the effects of cognitive control training on emotional vulnerability, reports that repeated training is a promising preventive intervention for a disorder like depression, notwithstanding that efficacy could be improved.

A frequently used training paradigm is the adaptive dual n-back task (Jaeggi, Buschkuhl, Jonides, & Perrig, 2008) in which individuals are presented with two streams (visual and auditory) of information simultaneously. Participants are required to compare the visual and auditory information from the current trial with ' $n$ ' trials back (e.g. 2 trials back) and indicate whether there is a match. Importantly, the task becomes progressively more difficult with increases in performance, as the level of  $n$  increases (Jaeggi et al., 2008). Adaptive dual n-back training has shown to increase working memory capacity in dysphoric individuals, with training effects transferring to a change detection working memory task which requires the filtering of irrelevant distracting information (Owens, Koster, & Derakshan, 2013). An emotional version of the dual n-back task, with emotional faces as visual information and emotional words as auditory information, improved emotion regulation in response to negative film clips, both in terms of subjective levels of distress and in terms of an increase in activation in frontal brain areas involved in affective control (Schweizer, Grahm, Hampshire, Mobbs, & Dalgleish, 2013). Sari, Koster, Pourtois, and Derakshan (2016) found that the adaptive dual n-back training improved attentional control as measured by a Flanker task and as indicated by changes in resting state electroencephalography. Moreover, the degree of improvement on this neutral working memory training task correlated with greater reduction in self-reported trait anxiety across the training period (Sari, Koster, Pourtois, et al., 2016). A recent study found that a worry induction impaired working memory capacity and this was mediated by self-reported levels

of state worry and anxiety (Sari, Koster, & Derakshan, 2016). Taken together, these findings support the proposition that impaired attentional control is associated with anxiety and worry, and that worry itself further impairs attentional control, turning this into a cycle that maintains worry episodes.

Both impaired attentional control and the presence of negative emotional processing biases thus seem to be risk factors for pathological worry, and their interplay may be ‘toxic’ in terms of initiating and maintaining worry episodes (Hirsch & Mathews, 2012; see also Eysenck et al, 2007). Hirsch and Mathews (2012) proposed that in worry-prone individuals, negative emotional processing biases can activate threat representations in response to external cues or internal reminders of threat. Such threat representations may compete for attention with currently activated information about ongoing tasks or benign topics, with the stronger or more active representation inhibiting the weaker representation. In worry-prone individuals the strength of negative emotional processing biases contributes to a greater activation of the threat representation, while at the same time impaired attentional control may be insufficient to maintain activation of task-related or benign representations (Hirsch & Mathews, 2012). The strongly activated threat representation is thus more likely to inhibit the currently activated task-related representation, resulting in distraction and the threat representation becoming stronger and intruding into awareness. Moreover, impaired attentional control then reduces the likelihood that attention is redirected to the intended (task-related or benign) representation, leading to a failure to control negative intrusions from developing into a worry episode (Berggren & Derakshan, 2013).

### **The current investigation**

While both negative emotional processing biases (e.g. interpretation bias), and reduced attentional control resources have been shown to contribute to excessive worry, these two cognitive processes have typically been studied in isolation. However, based on cognitive

models of anxiety and worry (Hirsch & Mathews, 2012) it seems that interpretation bias and attentional control contribute to excessive worry in a different manner. While negative emotional processing biases contribute to activation of threat representations, increasing the likelihood that worrying thoughts intrude into awareness, impaired attentional control reduces the likelihood that attention is redirected to the intended representation, leading to impaired control of negative intrusions once activated. The aim of the current study was therefore to investigate how modulation of interpretation bias and working memory capacity influences the tendency to worry, and examine whether these two processes have a different influence on the experience of negative intrusive thoughts.

We investigated whether ten sessions of training could effectively increase positive interpretation bias and/or working memory capacity in a sample of worry-prone individuals who were preselected based on their responses on the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990). Our main research question was whether training induced changes in working memory or interpretation bias transferred (i.e. far transfer) to a behavioural measure of the tendency to worry. For the working memory training we used an adaptive dual n-back task (Jaeggi et al., 2008; Sari, Koster, Pourtois, et al., 2016), while for the CBM-I training we used an ambiguous scenario task (Hayes et al., 2010; Hirsch et al., 2009). Participants in a control training condition (control condition) received a combination of sham working memory training and sham CBM-I. An active working memory training condition (WMT condition) received adaptive working memory training along with sham CBM-I, while participants in the active cognitive bias modification training condition (CBM-I condition) received active CBM-I and sham working memory training. Based on previous studies (Jaeggi et al., 2008; Owens et al., 2013; Sari, Koster, Pourtois, et al., 2016) we expected individuals in the WMT condition to show a significant increase in the mean n-back level across the training sessions (individuals who receive sham



training will remain at level  $n = 1$ ). Similarly, based on previous findings (Hayes et al., 2010) we expected the CBM-I condition, as compared to the WMT and control conditions, to show an increase in positivity bias during training.

We examined near transfer of training related improvements to a frequently used measure of working memory capacity, the change detection task (Owens et al., 2013; Vogel, McCollough, & Machizawa, 2005), and a measure of interpretation bias, the scrambled sentence task (Wenzlaff & Bates, 1998). We hypothesized that the WMT condition, as compared to the CBM-I and control conditions, would show increases in performance on the change detection task, especially on more difficult trial types that require more filtering of information. Previous research also found that CBM-I training, as compared to control training, was related to greater attentional control on a random key press task during worry (Hirsch et al., 2009). Based on these findings, we expected that the CBM-I condition, as compared to the control condition, would show increased performance on the change detection working memory task, but to a lesser extent than the WMT condition. In terms of interpretative bias, we hypothesized that the CBM-I condition, as compared to the WMT and control conditions, would show a significant increase in positive interpretation bias as measured with the scrambled sentence task.

In order for cognitive training to be clinically relevant, it's important to show that training related changes also transfer to measures of worry and anxiety (far transfer). We used self-report measures of worry, anxiety, and attentional control, expecting both the WMT and CBM-I conditions, as compared to the control condition, to show a decrease in worry and anxiety, and an increase in attentional control. Our main outcome measure was a behavioural measure of the tendency to worry, the breathing focus task (BFT), which is less sensitive to self-report bias (Borkovec et al., 1983; Hirsch et al., 2009; Ruscio & Borkovec, 2004). With this BFT, we assessed the experience of negative intrusive thoughts, both before and after a

period in which worrying thoughts were activated. This allowed us to examine the overall level of experienced negative intrusions, as well as the reactivity of negative intrusive thoughts across a period when worrying thoughts are activated. We expected that participants in both the WMT and CBM-I conditions, as compared to the control condition, would experience less negative intrusions. More specifically, we expected the CBM-I condition to show a general reduction in negative intrusions based on previous research (Hirsch et al., 2009). For the WMT condition we expected a decrease in reactivity of negative intrusive thoughts across a worry period, corresponding with the idea that once worry thoughts are activated, improved attentional control can attenuate negative intrusions by redirecting attention to the task at hand or towards more benign information.

In addition to investigating the effect of training condition on the BFT, we also tested how individual differences in training related changes in working memory capacity and interpretation bias influenced the tendency to worry. This allows us to explore whether training induced changes in the underlying cognitive processes, taking into account inter-individual differences in training effectiveness, transfer to changes in the tendency to worry (see also the discussion on separating procedure from process in attentional bias modification, Grafton et al., 2017; MacLeod & Grafton, 2016). Across all individuals we expected greater increases in positive interpretation bias, as measured with the scrambled sentence task, to be related to overall less negative intrusive thoughts. Likewise, we expected greater increases in working memory capacity, especially on the difficult trial types of the change detection task, to relate to reduced reactivity of negative intrusive thoughts across a worry period.

## **Method**

### **Participants**

Individuals were first pre-screened using the PSWQ (Meyer et al., 1990) and considered eligible for participation if they had a score of 56 or above. This criterion was based on previous research with a college sample in which a score of 56 was one standard deviation below the mean of individuals with a GAD diagnosis (Molina & Borkovec, 1994), and in line with previous research in high worriers (Hirsch, Hayes, & Mathews, 2009). Based on this criterion 81 individuals were selected for participation. All participants completed the PSWQ again during the first test session and based on this assessment 15 participants were excluded from further participation as they no longer met the selection criterion. Additionally, six participants dropped out from the study for other reasons (e.g. underestimating the time investment for doing the training task). The remaining 60 participants (52 females), aged between 18 and 40 ( $M = 23.17$ ,  $SD = 4.01$ ), completed the study. Participants were paid for their participation. The experiment was approved by the ethical committee of the University of Oxford, MSD-IDREC-C1-2014-106 (R44129/RE001).

## **Materials**

**Participant characteristics: baseline questionnaire measures.** We assessed the presence and severity of depressive symptoms in the previous two weeks using the 21-item Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996), with possible scores ranging from 0 to 63. The internal consistency of the BDI-II in the current sample was excellent, Cronbach's  $\alpha = .90$ .

The Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) was used to assess the tendency for perseverative thinking. This questionnaire consists of 15 statements that participants have to rate on a 5-point scale (0-4), ranging from “never” to “almost always”, resulting in a total score ranging from 0-60. The internal consistency of the PTQ in the current sample was excellent, Cronbach's  $\alpha = .93$ .

To assess the different domains participants worry about, we used the 25-item Worry Domain Questionnaire (WDQ; Tallis, Davey, & Bond, 1994). People have to indicate to what extent they worry about things described in each item, on a 5-point scale (i.e. 1-5) ranging from “not at all” to “extremely.” Five subscales are then calculated that refer to different worry domains: relationships, lack of confidence, aimless future, work, and financial. The score on each subscale can range from 5-25. For the current sample the internal consistency was questionable for the relationship domain,  $\alpha = .65$ , good for the lack of confidence domain,  $\alpha = .81$ , acceptable for the aimless future domain,  $\alpha = .72$ , good for the work domain,  $\alpha = .80$ , and good for the financial domain,  $\alpha = .86$ .

Symptoms of Generalized Anxiety Disorder were assessed with the 9-item Generalized Anxiety Disorder Questionnaire (GAD-Q-IV; Newman et al., 2002). We scored the GAD-Q-IV using a total sum score. Items 1-4 and item 6 are yes/no items, in which “yes” was coded as 1 and “no” was coded as 0. For item 5 participants have to list their most frequent worry topics (up to 6 topics). One point was given for each listed topic and the total was divided by 3. In item 7 participants had to indicate whether in the last six months they had often been bothered by physical symptoms (six different types of symptoms were listed). Similarly, to item 5, 1 point was given for each physical symptom they experienced up to 6 points, and the total was again divided by 3. Items 8 and 9 ask participants about the degree of stress and interference and have to be rated on a scale ranging from 0 “none” to 8 “very severe” and were each divided by 4. This led up to a total score ranging from 0-13. The internal consistency of the GAD-Q-IV in the current sample was acceptable, Cronbach’s  $\alpha = .76$ .

**Training.** The training task consisted of a combination of (adaptive or sham) working memory training and (active or sham) cognitive bias modification for interpretation bias. The

order of training tasks, starting with the working memory task or the CBM-I task, was counterbalanced across participants.

***Dual n-back training.*** We used a dual n-back task (Jaeggi et al., 2008) to train working memory capacity over multiple sessions (similar procedure to Owens et al., 2013). In this task participants are presented with a 3x3 grid with a cross in the centre of the grid, serving as fixation point. In each trial a green square is presented at one of eight different locations in this grid and simultaneously one of eight consonants is spoken (c, h, k, l, q, r, s, and t) at a rate of 500 msec. There was a 2500 msec intertrial interval. Participants were required to remember both the location of the green square and the spoken letter for each trial, and had to respond when either of these stimuli matched the location of the green square or spoken letter on  $n$  trials back in the trial sequence. Participants had to press “A” if the location of the green square matched and “L” if the spoken letter matched, and they were instructed to press both keys if both the visual and auditory stimuli matched. If there was no match participants made no response. Targets were set pseudorandomly to ensure that each block had an equal number of matches (4 per block) for the visual and auditory modality, and additionally two trials in which both the visual and auditory stimulus matched stimuli  $n$ -trials back. Target positions were presented in a pseudorandom order to ensure the value of  $n$  was the same for both the visual and auditory stimuli. Participants were instructed to try to respond as quickly and accurately as possible, and they received an online summary of their percentage accuracy across blocks at the end of each session (for each modality separately).

An adaptive version of the dual n-back task was used as the active working memory training, while a version of the task in which the dual n-back level stays at 1 (i.e. 1-back) was used as the sham training. All participants began each training session at the 1-back level, but after the first block participants who received the adaptive dual n-back version (WMT condition) could potentially reach a maximum level of 4-back. The level of  $n$  was increased

across blocks if accuracy for both modalities (visual and auditory) was at or above 95%. The level of  $n$  was decreased if accuracy for either modality fell below 75%, while the level remained the same if accuracy was between 75% and 95%. Before the start of each block, participants were presented with the upcoming  $n$ -back level, which remained visible throughout the block.

All participants who used a web link for training for the first time, completed a practice block on the dual 1-back level, after which participants would only have test blocks. Each test block consisted of  $20 + n$  trials, and participants had to complete 15 test blocks during each training session. There was a 15 sec break between blocks, so the working memory part of the training lasted approximately 20 mins.

***Cognitive bias modification-interpretation.*** We used a training task in which participants listened to auditory scenarios that were designed to induce an interpretation bias (based on, Hirsch et al., 2009). Training scenarios remained ambiguous in terms of their emotional interpretation until the last word, which then determined either a positive or negative meaning. Following the scenario, participants had to answer a comprehension question with a yes/no answer within 10 secs. If participants correctly answered (according to the positive or negative meaning of the scenario), a green frame appeared accompanied by a beep tone, while a red frame accompanied by a buzzing tone indicated an incorrect answer. The feedback served to reinforce the intended interpretation of the scenario. An example of a positive training scenario is:

“You have been practising rowing and want to qualify for the college team. You train as hard as you can and when the results come in, you are *pleased*.”

The negative version of this scenario would have ended with “disheartened.” This scenario was followed by the comprehension question “Do you have a shot?” which for the positive scenario was correctly answered with “yes”, while for the negative version the correct answer

would be “no.” Participants in the CBM-I condition would only get positive training scenarios, while participants receiving the sham CBM-I version would have 50% scenarios with a positive meaning and 50% scenarios with a negative meaning (Hirsch et al., 2009).

Each training session also included eight catch items consisting of scenarios that remained ambiguous (based on, Hayes et al., 2010a). The answer to the comprehension question then provides an indication of how participants interpreted the scenario, that is, in a positive or negative manner. An example of a catch trial is:

“You have an oral exam. You have studied a lot for this test but some of the questions remain tricky. As you look into your professor’s eyes you can easily see what she is thinking.”

This catch scenario was then followed by a comprehension question “Will you fail the exam?” A “yes” answer would indicate a negative interpretation of the scenario, whereas “no” indicated a positive interpretation. Participants in the CBM-I condition received positive feedback if their answer indicated a positive interpretation and negative feedback if they had interpreted the scenario in a negative manner, which served to reinforce positive interpretations. Participants receiving the sham CBM-I version received positive feedback regardless of their answer, thus not specifically reinforcing either a positive or negative interpretation. From these catch items we calculated a positivity index reflecting the ratio of positively interpreted catch items on the total number of catch items (Hayes et al., 2010).

Each training session consisted of 66-70 auditory scenarios which included 8 catch items. Throughout the session participants were able to take a break at three time points, and the CBM-I part of the training lasted approximately 30 mins.

**Near transfer: change detection task.** We used the change detection task (CDT; as developed by Vogel et al., 2005; and used by Owens et al., 2013) to measure working memory capacity. In each trial, participants first saw a fixation cross in the centre of the screen with an arrow above it pointing either left or right (700 msec). Participants were

instructed to attend to the side that the arrow indicated. Following this, either two or four rectangles (memory array) appeared at both the left and right side of the screen (100 msec) and participants were instructed to remember the orientation of the red rectangles on the attended side. After a short retention period (900 msec), the rectangles reappeared on the screen (test array) and participants had to indicate whether the orientation of one of the red rectangles they had memorized had changed or not, by pressing either the “f” or “j” key. Response keys were counterbalanced across participants. Participants had a maximum of 2000 msec to give their response and were instructed to respond as fast and accurately as possible. The intertrial interval randomly varied between 1500 and 2000 msec in steps of 100 msec.

The task included three array types; a two item, four item, and distractor condition. In the two and four item condition all rectangles were red, while the distractor condition consisted of four rectangles, two red rectangles and two blue distractor rectangles. The rectangles were presented on a black background, and appeared within a 156 x 288 pixel rectangular region. The rectangles could appear in four possible orientations, horizontal, vertical, 45° left and 45° right tilted. There were 64 stimuli for each of the trial types. All possible trial types, depending on array type, arrow direction, and whether there was a change or no change of target items, appeared equally often in the task. The task included 24 practice trials and 192 test trials divided over 4 test blocks.

**Near transfer: scrambled sentence task.** To assess the accessibility of positive interpretations of ambiguous material, we used a computerized version of the Scrambled Sentence Task (SST; Wenzlaff & Bates, 1998). Scrambled sentences consisting of six words were presented on the screen and participants had to form correct sentences consisting of five words, leaving out one word. Participants could form the sentence by clicking on the words they wished to use. Once they had submitted their answer they could not correct the sentence



anymore and would automatically move on to the next sentence. On every trial, two correct sentences could be formed, with either a positive or a negative solution. Participants were instructed to form propositions and not interrogative sentences, and that each sentence could be formed in several ways but they have to choose. They were instructed to work as quickly as possible because time was restricted. Participants had a maximum of 4 mins to complete the task. Furthermore, participants were given a 6-digit number to remember at the beginning of the task to increase the cognitive load in order to undermine participants' tendency to suppress negative solutions in the task (cf. Wenzlaff & Bates, 1998). At the end of the task they were asked to recall this number. There were two lists of 20 scrambled sentences and the order of administration prior to and after training was counterbalanced.

**Far transfer: breathing focus task.** To assess the tendency to worry we used a version of the BFT (Hirsch et al., 2009) which is an adaptation of a previously developed behavioural measure of worry (Borkovec et al., 1983; Ruscio & Borkovec, 2004). After instructions, participants first do a 20-sec practice period in which they were asked to just focus on their breathing. This is followed by another 45-sec practice period in which at three random time intervals participants had to indicate whether they were focused on their breathing or whether they experienced a thought intrusion. The actual task then began with a 5 min breathing focus period in which participants were asked to focus on their breathing. During this period a beep tone would signal participants to report whether at that moment they were focusing on their breathing or were experiencing a thought intrusion. If their thoughts had wandered they were required to indicate whether the thought was positive, neutral, or negative, and to give a very brief description of what they were thinking about. A total of 12 tones occurred at random intervals between 20 and 30 secs. At the end of this first breathing focus period, participants rated their mood (anxious, depressed, happy) on a 0-100 visual analogue scale with “not at all anxious” to “extremely anxious” (or depressed/happy)

as anchor points. Additionally, they were asked to “estimate the % to which you were able to focus on your breathing (0% not at all – 100% all of the time)”, “rate how difficult you found focussing on your breathing (0 not at all difficult – 100 extremely difficult)”, and “estimate the % of time you spent worrying during the last 5 minutes (0% none of the time – 100% all of the time).”

Following this, participants were instructed to identify a topic that they currently worry about in their life and discuss this briefly with the experimenter to make sure it was suitable for the task (i.e. related to a potential negative, future situation). Participants were then asked to continue to worry about this topic for a 5 min period. During this worry period, the experimenter left the room. After 5 mins the experimenter returned and a second breathing focus period was completed, including similar ratings as following the first breathing focus period. Following these ratings, participants were also asked to rate their mood in relation to the worry period, using the same type of mood rating scales as described above. Additionally, participants were asked to “estimate the % to which you were able to spend worrying (0% not at all – 100% all of the time)”, “rate how difficult you found it to worry for 5 minutes (0 not difficult at all – 100 extremely difficult)”, “rate how stressed you were whilst worrying (0 not stressed at all – 100 extremely stressed), and “what % of the time were your thought contents – negative/positive/neutral” (0-100%). Finally, participants were asked to provide more extensive descriptions of their thought intrusions during the two breathing focus periods. The experimenter would read aloud the short descriptions the participant had given during the breathing focus periods and participants were asked to recall in more detail what they were thinking at the time. These more detailed descriptions were also recorded.

**Far transfer: questionnaire measures.** At baseline and post-training we assessed state and trait anxiety with the State and Trait Anxiety Inventory (STAI; Spielberger,

Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were asked to rate how they feel “*in general*” on a 4-point scale ranging from “almost never” to “almost always” (trait version) and “*at this moment*” on a 4-point scale ranging from “not at all” to “very much so” (state version). Both versions consist of 20 items, each with a possible total score ranging from 20-80. The internal consistency of the STAI-state in the current sample was excellent, both at baseline, Cronbach’s  $\alpha = .93$ , and at post-training,  $\alpha = .94$ . Similarly, the internal consistency of the STAI-trait was good at baseline,  $\alpha = .89$ , and excellent at post-training,  $\alpha = .92$ .

The PSWQ (Meyer et al., 1990) was used to assess the tendency to worry for screening potential participants, and the scale was administered again at baseline and post-training. This 16-item questionnaire asks participants to rate statements on a 5-point scale ranging from “not at all typical of me” to “very typical of me.” A total score is calculated ranging from 16-80. The internal consistency of the PSWQ in the current sample was acceptable at baseline,  $\alpha = .78$ , and good at post-training,  $\alpha = .89$ .

Finally, we also assessed self-reported attention control at baseline and post-training by means of the 20-item Attentional Control Scale (ACS; Derryberry & Reed, 2002). Participants indicated how strongly statements apply to them on a 4-point scale ranging from “almost never” to “almost always.” A total score is calculated ranging from 20-80. The internal consistency of the ACS in the current sample was acceptable at baseline,  $\alpha = .78$ , and good at post-training,  $\alpha = .86$ .

## **Procedure**

Participants were recruited using advertising at the University of Oxford campus and colleges. Individuals were pre-screened using the PSWQ and if the cut-off criterion was met, they were invited to take part in the study. During the first test visit, participants were randomized to the Control, WMT, or CBM-I training condition. After informed consent, participants filled out the baseline questionnaires. Participants who no longer met the

eligibility criterion (i.e. score of 56 or above on the PSWQ) completed the first test session but were told that they could not continue their participation. Following the questionnaires, participants performed the CDT, SST, and finally the BFT. Afterwards, participants received instructions on the training task. Instructions were dependent on which training condition participants were in. Additionally, participants performed a practice block of the 1-back or n-back task (depending on training condition).

The day after the test session participants started with the 10-day online training at home. Participants completed each full training session in one go. Every morning participants received a training reminder by email. The first time participants used the web link to access the online training, they had to fill out their participant number. The experimenter monitored participants' training performance on a daily basis, and if participants missed a training session they would be asked to make up for it by doing the training task twice on one of the following days. Participants had to complete at least seven sessions of both the working memory part and the CBM-I part.<sup>1</sup> During the second test visit (always 11 days after the first test visit) participants first completed the trait and state version of the STAI, the PSWQ, and the ACS. Following this, participants again completed the CDT, SST, and BFT. At the end participants were fully debriefed about the study.

## **Results**

### **Participant Characteristics**

Means and standard deviations for baseline variables are presented in Table 1. To test for pre-existing differences between the three conditions, univariate ANOVAs were performed with condition entered as a between-subjects factor. We performed a multivariate ANOVA on the WDQ subscales. No significant differences were found between the

---

<sup>1</sup> One participant in the control condition completed six sessions of the (sham) working memory part and (sham) CBM-I part. One participant in the WMT condition completed 5 sessions of the (sham) CBM-I part, but did complete nine sessions of the (adaptive) working memory part. One participant in the CBM-I condition completed six sessions of the (active) CBM-I part, but ten sessions of the (sham) working memory part.

conditions in age or questionnaire scores at baseline, all  $ps > .10$ , but there was a trend for differences in gender distribution across conditions,  $\chi^2(2, N = 60) = 5.48, p = .081, \phi_c = .30$ .

Table 1

*Participant Characteristics at Baseline*

	Control ( $n = 20$ )	WMT ( $n = 20$ )	CBM-I ( $n = 20$ )
	$M (SD)$	$M (SD)$	$M (SD)$
Age	22.30 (3.39)	23.85 (3.87)	23.35 (4.72)
Gender	15 females	17 females	20 females
BDI	12.70 (9.34)	14.10 (10.15)	13.90 (8.63)
STAI trait	51.25 (10.59)	54.55 (8.74)	54.70 (8.11)
STAI state	46.45 (11.45)	45.95 (12.77)	44.80 (10.31)
ACS	46.15 (8.88)	43.30 (8.79)	44.30 (6.70)
PSWQ	67.25 (6.22)	66.95 (7.31)	67.90 (6.47)
PTQ	36.20 (12.66)	41.35 (9.29)	36.20 (9.75)
GAD-Q-IV	8.29 (2.17)	8.96 (2.51)	8.59 (2.07)
WDQ relationships	13.30 (4.70)	14.30 (4.78)	14.40 (4.21)
WDQ lack of confidence	17.25 (4.30)	15.55 (5.84)	17.55 (4.06)
WDQ aimless future	15.25 (4.48)	16.80 (4.36)	16.15 (5.09)
WDQ work	16.70 (4.81)	16.60 (5.69)	19.40 (3.55)
WDQ financial	14.35 (5.62)	13.90 (4.75)	13.30 (5.36)

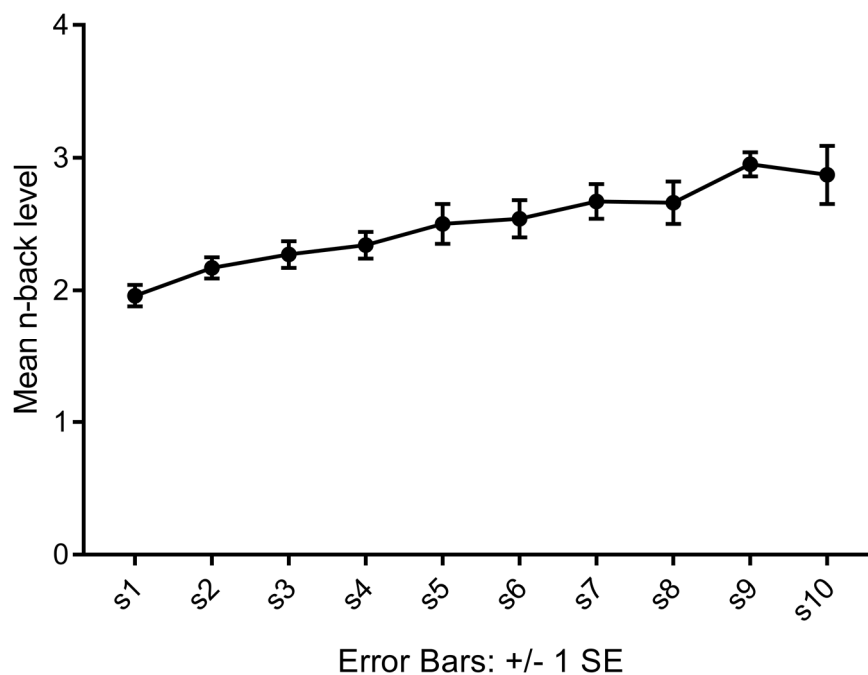
**Number of Training Sessions Completed**

A univariate ANOVA, with training condition as a between-subjects factor, showed no differences between training conditions in the number of dual n-back sessions (i.e.

working memory training) that were completed,  $F(2,57) < 1$ , n.s., nor in the number of CBM-I sessions that were completed,  $F(2,57) = 1.20$ ,  $p = .309$ ,  $\eta_p^2 = .04$ .

### Training: Dual N-back

Data was analysed separately for the WMT condition and the other two conditions, given that the Control and CBM-I condition remained at 1-back level by design. Figure 1 shows the changes in mean dual n-back level across the ten training sessions for the WMT condition. A repeated measures ANOVA with time (first vs. last session) as within-subject factor revealed that the WMT condition showed improvement in working memory, as indicated by mean dual n-back level, from their first training session ( $M = 1.96$ ,  $SD = 0.37$ ) to their last training session ( $M = 2.75$ ,  $SD = 0.72$ ),  $F(1,19) = 37.98$ ,  $p < .001$ ,  $\eta_p^2 = .67$ . The number of completed training sessions was related to the change in mean dual n-back level,  $r = .54$ ,  $p = .015$ , indicating that the more working memory training sessions participants in the WMT condition completed, the greater the increase in mean n-back level.



*Figure 1.* Mean dual n-back level (with 1 *SE*) across ten training days, for the working memory training condition.

To examine a change in effort for the Control and CBM-I training condition (where  $n$ -level = 1), we examined changes in the mean accuracy levels during the first training session ( $M = 94.53$ ,  $SD = 5.80$  and  $M = 97.52$ ,  $SD = 2.96$  respectively) and the last training session ( $M = 95.30$ ,  $SD = 4.58$  and  $M = 97.44$ ,  $SD = 2.26$  respectively). A mixed ANOVA with time (first session vs. last session) as within-subject factor and condition (Control vs. CBM-I) as between-subjects factor revealed no main effect of time,  $F(1,38) = 0.15$ ,  $p = .704$ ,  $\eta_p^2 < .01$ , nor did this interact with condition,  $F(1,38) = 0.23$ ,  $p = .636$ ,  $\eta_p^2 < .01$ . However, there was a main effect of condition,  $F(1,38) = 10.67$ ,  $p = .002$ ,  $\eta_p^2 = .22$ , indicating that overall the CBM-I condition had higher accuracy on the 1-back training task.

### **Near Transfer: Change Detection Task**

Performance on the CDT was measured by calculating K-scores following the widely used formula (Pashler, 1988),  $K = \text{array size} \times (\text{hits} - \text{false alarms}) / (1 - \text{false alarms})$ . K is thus dependent on the array size, and we calculated K for the two-item, four-item, and distractor condition separately (array size 2, 4, and 2 respectively). The validity of Pashler's K is constrained by the assumption that hit rate > false alarm rate, and that the false alarm rate < 1. This led us to exclude one participant from the control condition during analyses on the CDT. We performed a mixed ANOVA on the K-measure with trial type (two, four, distractor) and time (pre-training vs. post-training) as within-subject factors, and condition (Control vs. WMT vs. CBM-I) as between-subjects factor. This ANOVA<sup>2</sup> showed a main effect of trial type,  $F(2,53) = 40.57$ ,  $p < .001$ ,  $\eta_p^2 = .61$ , a main effect of time,  $F(1,54) = 20.76$ ,  $p < .001$ ,  $\eta_p^2$

---

<sup>2</sup> Results are reported after excluding 2 multivariate outliers (>3 *SDs* on standardized residuals), one participant from the WMT training condition and one participant from the CBM-I training condition.

= .28, a Trial type x Time interaction,  $F(2,53) = 10.40, p < .001, \eta_p^2 = .28$ , while the hypothesized Condition x Time interaction was not significant,  $p > .05$ . To follow up the Trial type x Time interaction, we performed three mixed ANOVAs, separately for the two, four, and distractor trial types, with time (pre-training vs. post-training) as within-subject factor and condition (Control vs. WMT vs. CBM-I) as between-subjects factor. For the two-item trial type, there was no effect of time nor did this interact with training condition, all  $ps > .10$ . For the distractor-item trial type the mixed ANOVA revealed a main effect of time,  $F(1,54) = 16.65, p < .001, \eta_p^2 = .24$ , reflecting a general increase across training conditions (pre  $M = 1.54, SD = 0.38$ ; post  $M = 1.72, SD = 0.22$ ). For the four-item trial type the mixed ANOVA also revealed a main effect of time,  $F(1,54) = 19.28, p < .001, \eta_p^2 = .26$ , reflecting a general increase across training conditions (pre  $M = 2.04, SD = 0.80$ ; post  $M = 2.46, SD = 0.70$ ). Additional analyses on the relationship between change in performance on the dual n-back training task (from the 1<sup>st</sup> to last training session) and change in performance on the CDT (from pre- to post-training) can be found in supplemental material (S1) made available online.

### **Training: CBM-Interpretation**

We examined changes in performance on catch trials (i.e. positivity index) from participants' first training session to the last training session. Figure 2 shows the changes in positivity index across the ten training sessions for the three training conditions. A mixed ANOVA with time (first vs. last session) as within-subject factor and condition (Control vs. WMT vs. CBM-I) as between-subjects factor showed a significant Time x Condition interaction,  $F(2,57) = 4.51, p = .015, \eta_p^2 = .14$ . Bonferroni corrected Paired samples t-tests revealed that only the CBM-I condition showed a significant increase in positivity index over time (first  $M = 0.59, SD = 0.23$ ; last  $M = 0.82, SD = 0.23$ ),  $t(19) = 3.27, p = .004, d = 1.00$ , while neither the Control condition (first  $M = 0.41, SD = 0.21$ ; last  $M = 0.38, SD = 0.24$ ),



$t(19) = 0.74, p = .467, d = 0.16$ , nor the WMT condition (first  $M = 0.44, SD = 0.26$ ; last  $M = 0.43, SD = 0.29$ ),  $t(19) = 0.04, p = .971, d = 0.01$  showed an increase in positivity bias. The number of completed CBM-I training sessions was not related to the change in performance on the catch trials across training,  $r = .06, p = .637$ .

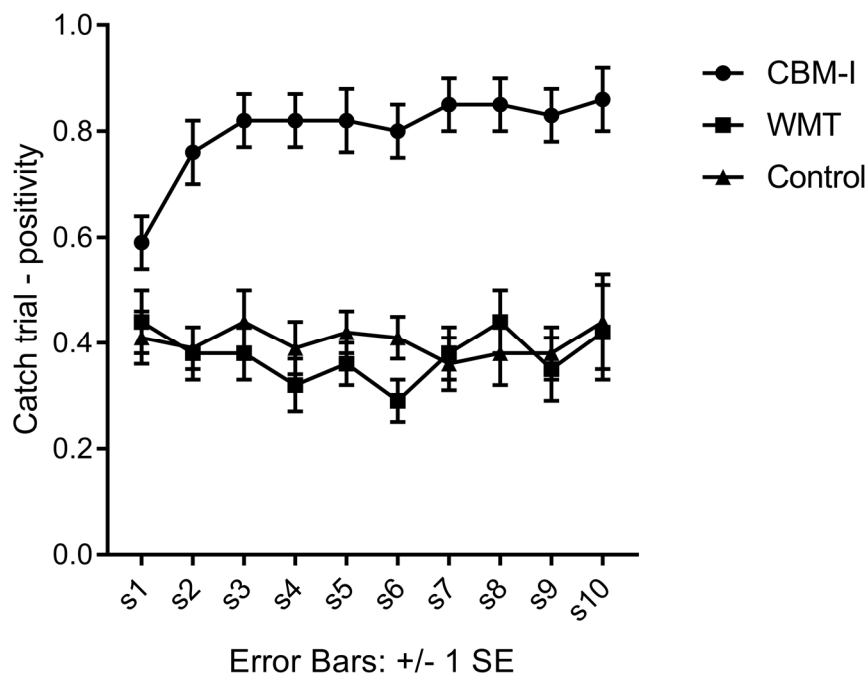


Figure 2. Positivity index across ten training days, for the three training conditions.

### Near Transfer: Scrambled Sentence Task

A positivity index was calculated reflecting the ratio of correctly formed sentences with a positive solution on the total of correctly formed sentences. A mixed ANOVA on the positivity index with time (pre-training vs. post-training) as within-subject factor and condition (Control vs. WMT vs. CBM-I) as between-subjects factor showed a significant main effect of time,  $F(1,57) = 4.97, p = .030, \eta_p^2 = .08$ , and a Time x Condition interaction,  $F(2,57) = 4.84, p = .011, \eta_p^2 = .15$ . This interaction was driven by the CBM-I training condition showing a significant increase on the positivity index from pre- to post-training (pre  $M = 0.55, SD = 0.19$ ; post  $M = 0.71, SD = 0.20$ ),  $t(19) = 4.16, p = .001, d = 0.79$ ,

whereas neither the Control condition (pre  $M = 0.63$ ,  $SD = 0.22$ ; post  $M = 0.61$ ,  $SD = 0.21$ ),  $t(19) = 0.51$ ,  $p = .619$ ,  $d = 0.11$ , nor the WMT condition (pre  $M = 0.62$ ,  $SD = 0.23$ ; post  $M = 0.65$ ,  $SD = 0.22$ ),  $t(19) = 0.76$ ,  $p = .454$ ,  $d = 0.13$  showed a change. Additional analyses on the relationship between change on the CBM-I training catch trials and change in performance on the SST (from pre- to post-training) can be found in supplemental material (S1) made available online.

### **Near Transfer: Summary**

The WMT condition showed improved training performance as reflected by an increase in n-back level while the other training conditions remained at 1-back by design. Unexpectedly, all training conditions showed an increase in performance on the distractor and four-item trial types of the CDT. In terms of performance on the SST, the results were as expected with only the CBM-I condition showing a significant increase in positivity index across training.

### **Far Transfer: Self-Report Measures**

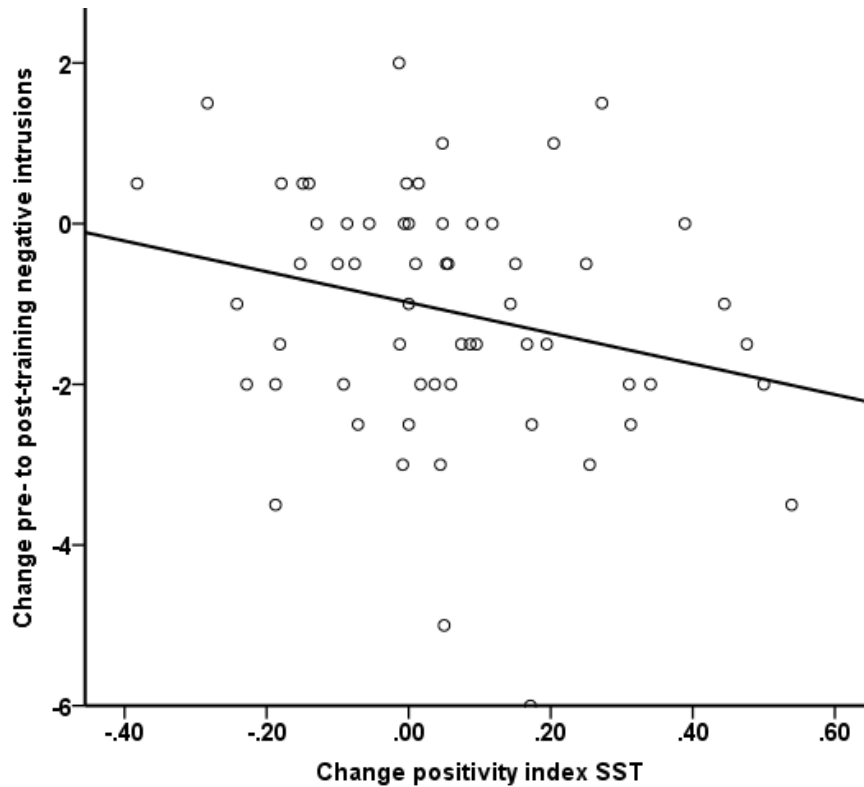
A mixed ANOVA with time (pre-training vs. post-training) as within-subject factor and condition (Control vs. WMT vs. CBM-I) as between-subjects factor was performed to examine changes in self-report measures across the training period. For trait anxiety (STAI trait) we observed a significant main effect of time,  $F(1,57) = 19.63$ ,  $p < .001$ ,  $\eta_p^2 = .26$ , and a Time x Condition interaction,  $F(2,57) = 3.23$ ,  $p = .047$ ,  $\eta_p^2 = .10$ . Bonferroni corrected paired t-tests, revealed that the CBM-I condition showed a decrease in trait anxiety from pre- to post-training (pre  $M = 54.70$ ,  $SD = 8.11$ ; post  $M = 48.85$ ,  $SD = 9.85$ ),  $t(19) = 4.25$ ,  $p < .001$ ,  $d = .63$ , while the Control condition (pre  $M = 51.25$ ,  $SD = 10.59$ ; post  $M = 47.90$ ,  $SD = 9.53$ ),  $t(19) = 2.17$ ,  $p = .043$ ,  $d = .33$ , and the WMT condition did not show a significant change (pre  $M = 54.55$ ,  $SD = 8.74$ ; post  $M = 53.50$ ,  $SD = 9.29$ ),  $t(19) = 1.01$ ,  $p = .324$ ,  $d = .12$ . For PSWQ scores the analysis showed a main effect of time,  $F(1,57) = 12.41$ ,  $p = .001$ ,  $\eta_p^2 = .18$ ,

reflecting a general decrease in self-reported tendency to worry from the pre- ( $M = 67.37$ ,  $SD = 6.58$ ) to post-training ( $M = 64.13$ ,  $SD = 8.98$ ). Finally, for attentional control (ACS) we observed a significant main effect of time,  $F(1,57) = 7.19$ ,  $p = .010$ ,  $\eta_p^2 = .11$ , and a Time x Condition interaction,  $F(2,57) = 6.38$ ,  $p = .003$ ,  $\eta_p^2 = .18$ . Bonferroni corrected paired t-tests, separately per training condition, showed that only the CBM-I condition reported a significant increase in attentional control (pre  $M = 44.30$ ,  $SD = 6.70$ ; post  $M = 48.80$ ,  $SD = 8.85$ ),  $t(19) = 3.67$ ,  $p = .002$ ,  $d = .54$ . Neither the Control condition (pre  $M = 46.15$ ,  $SD = 8.88$ ; post  $M = 47.45$ ,  $SD = 9.89$ ),  $t(19) = 1.14$ ,  $p = .268$ ,  $d = .14$ , nor the WMT condition (pre  $M = 43.30$ ,  $SD = 8.79$ ; post  $M = 42.45$ ,  $SD = 7.67$ ),  $t(19) = 1.09$ ,  $p = .289$ ,  $d = .10$ , reported a significant change in attentional control.

### **Far Transfer: Breathing Focus Task**

We focussed our analyses on the number of negative intrusions that participants experienced during the BFT. Additional analyses on other rating scales that were administered during the BFT can be found in supplemental material (S1) made available online. A mixed ANOVA was performed on Log transformed data of the number of negative intrusions (because of skewed data), with reactivity (pre-worry vs. post-worry) and time (pre-training vs. post-training) as within-subject factors, and condition (Control vs. WMT vs. CBM-I) as a between-subjects factor. This analysis showed a main effect of reactivity,  $F(1,57) = 31.41$ ,  $p < .001$ ,  $\eta_p^2 = .36$ , indicating that there was an increase in negative intrusions across the worry period (untransformed pre-worry  $M = 1.76$ ,  $SD = 1.31$ ; post-worry  $M = 2.62$ ,  $SD = 1.69$ ). Additionally, a main effect of time was observed,  $F(1,57) = 29.98$ ,  $p < .001$ ,  $\eta_p^2 = .35$ , indicating that the overall number of negative intrusions decreased after training (untransformed pre-training  $M = 2.73$ ,  $SD = 1.78$ ; post-training  $M = 1.65$ ,  $SD = 1.33$ ). However, there was no significant Reactivity x Condition interaction,  $F(1,57) = 2.51$ ,  $p$

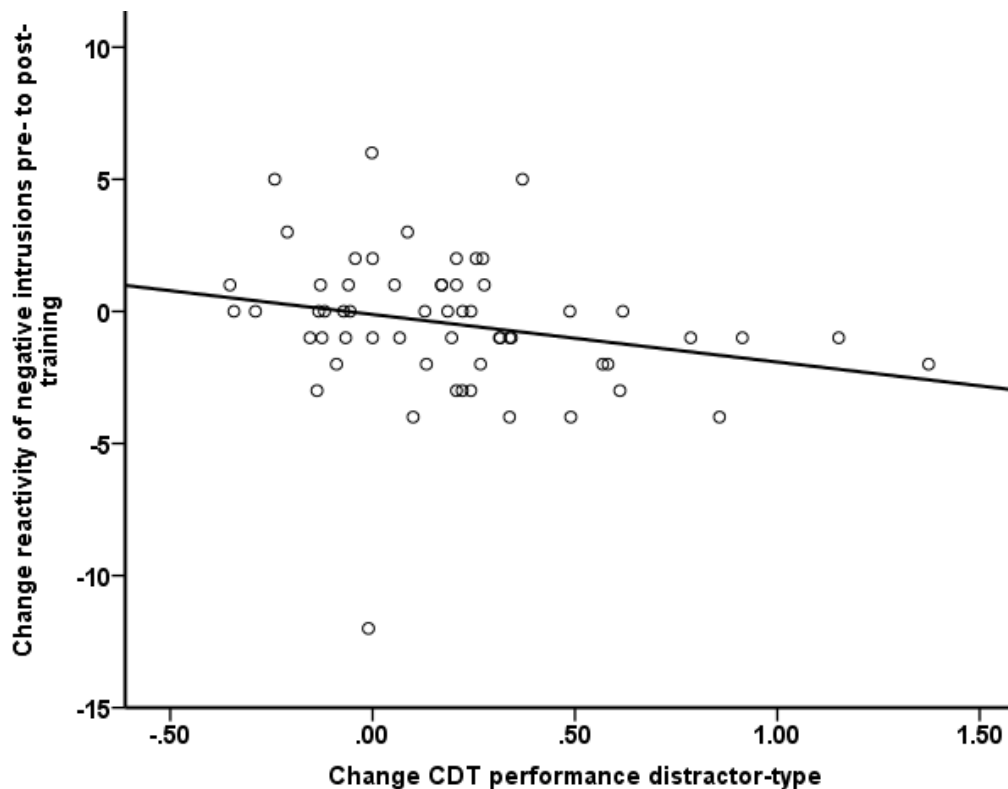
$= .090$ ,  $\eta_p^2 = .08$ , Time x Condition interaction,  $F(1,57) = 0.38$ ,  $p = .688$ ,  $\eta_p^2 = .01$ , nor a Reactivity x Time x Condition interaction,  $F(1,57) = 0.10$ ,  $p = .906$ ,  $\eta_p^2 < .01$ .



*Figure 3.* The change in Scrambled Sentence Task positivity index is negatively correlated with the change in negative intrusions (across the breathing periods). Untransformed data are presented.

**Individual differences in impact of training.** To take into account inter-individual differences in training effectiveness on working memory capacity and interpretation bias, we explored whether changes in performance on the CDT distractor-item and four-item trials, and changes in positivity index on the SST influenced the experience of negative intrusions. Mixed ANOVAs were performed on Log transformed data of the number of negative intrusions, with reactivity (pre-worry vs. post-worry) and time (pre-training vs. post-training) as within-subject factors, and the change in performance on the tasks as a covariate. Including

the positivity index on the SST showed a main effect of reactivity,  $F(1,58) = 25.03, p < .001$ ,  $\eta_p^2 = .30$ , a main effect of time,  $F(1,58) = 23.79, p < .001$ ,  $\eta_p^2 = .29$ , a Time x  $\Delta$  positivity index SST interaction,  $F(1,58) = 4.01, p = .050$ ,  $\eta_p^2 = .07$ , but the Reactivity x Time x  $\Delta$  positivity index SST interaction was not significant,  $F(1,58) = 3.05, p = .086$ ,  $\eta_p^2 = .05$ . The Time x  $\Delta$  positivity index SST interaction reflects a relationship between a greater increase in positivity index on the SST and a greater decrease in negative intrusions (across the breathing periods),  $r = -.25, p = .050$  (see Figure 3).



*Figure 4.* The change in performance on distractor-item trials in the Change Detection Task is negatively correlated with the change in reactivity of negative intrusions (i.e. from pre-worry to post-worry) across the training period. Untransformed data are presented.

Including the change in performance on the CDT distractor-item trials showed a main effect of reactivity,  $F(1,57) = 17.86, p < .001$ ,  $\eta_p^2 = .24$ , a main effect of time,  $F(1,57) =$

20.84,  $p < .001$ ,  $\eta_p^2 = .27$ , and a near significant Reactivity x Time x  $\Delta$  CDT distractor-item interaction,  $F(1,57) = 3.90$ ,  $p = .053$ ,  $\eta_p^2 = .06$ . This interaction indicates that a greater increase in performance on distractor-item trials was related to a greater decrease in reactivity of negative intrusions (i.e. the change from pre-worry to post-worry) over time,  $r = -.25$ ,  $p = .053$  (see Figure 4). Additional analyses whether changes in performance on the CDT distractor-item and four-item trials, and changes in positivity index on the SST correlate with the change in self-report measures of anxiety, worry, and attentional control can be found in supplemental material (S1) made available online.

### **Far Transfer: Summary**

Only the CBM-I condition showed a significant decrease in self-reported anxiety and attentional control across the training period, while all training conditions reported a decrease in worry. On the BFT, we observed a general increase in negative intrusions across the worry period and an overall decrease in negative intrusions across the training period, but this was not modulated by training condition. When exploring the effects of inter-individual differences in training related gains, we observed a relationship between a greater increase in positivity index on the SST and a greater overall decrease in negative intrusions. Additionally, we observed a relationship between a greater increase in performance on distractor-item trials on the CDT and reduced reactivity of negative intrusions across the training period.

### **Discussion**

This study aimed to investigate how training of positive interpretation bias and working memory capacity would influence the tendency to worry in high worry-prone individuals. The primary result was that neither of the active training conditions reduced worry in an objective behavioural assessment of worry relative to a control condition. Similarly, all conditions, including the control condition, led to a decrease in self-reported

worry. Nevertheless, there were some results indicating that active training may have potential in this domain. For instance, the results showed that participants receiving active CBM-I training showed a significant decrease in self-reported anxiety across the training period. Moreover, while there was no overall benefit of active cognitive training (CBM-I or adaptive WMT) relative to control training, there was some evidence that inter-individual differences in training-related improvements influenced the tendency to worry in our sample of high worriers. We observed a small to moderate relationship between greater increases in positive interpretation bias as measured with the SST and a greater decrease in negative intrusions in the behavioural assessment of worry. Similarly, increased performance on a measure of working memory capacity (CDT), specifically on the complex distractor trial type, was related to a reduction in reactivity of negative intrusions to a worry period.

Consistent with previous training studies using a similar CBM-I training paradigm (Hayes et al., 2010; Hirsch et al., 2009), participants in the CBM-I condition demonstrated a significant increase in positivity index across the training period, which transferred to an increase in the positivity index as measured by the SST across the training period. With regard to working memory training, individuals receiving control 1-back training showed stable accuracy levels over time, suggesting sustained effort even though the task was non-adaptive. Participants in the CBM-I condition generally performed better on the 1-back training task than the control condition, but both conditions showed high accuracy (i.e. around 95% or higher). Both training conditions remained at 1-back by design, so it is possible that this (small) difference in accuracy reflects differences in effort. Importantly, in the WMT condition we found a significant improvement in working memory performance (i.e. mean n-back level) across the training period, corresponding with previous studies using the dual n-back task (e.g. Jaeggi et al., 2008; Owens et al., 2013; Sari, Koster, Pourtois, et al., 2016). The number of completed working memory training sessions was correlated with this

improvement in mean n-back level, highlighting the potential importance of training compliance.

To demonstrate (near) transfer of working memory training effects to other tasks of working memory capacity we included the change detection task. No effect of training group, nor time, was observed for the easiest two-item trial type, possibly because of ceiling effects in performance. For the more difficult four-item and distractor-item trial types, a general improvement over time was observed but this was not modulated by training condition. Although we cannot exclude that this could be a test-retest effect across ten days, it may also imply that the sham training had a similar effect on increasing working memory capacity. It is possible that the sham dual 1-back training, in which one has to track two streams of information across trials, still led to improvements in working memory capacity, especially in this vulnerable group of worry-prone individuals. Moreover, participants were performing the training tasks each day, across 10 days, so improvements in attentional control resources in individuals receiving the sham training may also reflect more general effects such as adherence to a training schedule (Klingberg, 2010).

Determining a suitable control condition for working memory training, or CBM, remains a challenge. If a control condition is essentially a ‘low-dose’ training version (e.g. CBM-I including 50% positive and 50% negative training scenarios, potentially training flexibility) it may be harder to detect intervention effects. However, using an ‘active’ control group does provide more convincing evidence of the benefits of training than a comparison with an untreated control group or control training with very different task demands, because it controls for general effects (Melby-Lervåg et al., 2016). That is, an ‘active’ control training will better match the experimental training in terms of treatment credibility which could otherwise affect (inflate) the results by influencing participants’ outcome expectancies and thus lead to differences that may not reflect effects due to the trained process per se (Melby-



Lervåg et al., 2016; Mohr et al., 2009). Including additional control conditions that control for computer use, adherence to a training schedule, increase in task demands (e.g. adaptive task), etc., but train an unrelated process will be an important step for future training intervention research.

We also investigated whether training related effects would (far) transfer to self-reported changes in symptomatology and changes in the experience of negative intrusive thoughts as assessed with a behavioural measure. In terms of self-reported symptomatology, we observed that only the CBM-I condition showed a significant decrease in self-reported trait anxiety, and all training conditions showed a decrease in self-reported worry (i.e. PSWQ). Given that all training conditions were associated with a decrease in self-reported worry it is difficult to exclude the possibility that this reflects demand effects. Moreover, the average anxiety and worry scores remained relatively high after training (e.g. scores on the PSWQ are still above cut-off of 56). Interestingly, only the CBM-I condition, but not the WMT condition, was associated with a significant increase in attentional control as measured with the attentional control scale. Previous studies have also found improvements from CBM-I training on attentional control (Hirsch et al., 2009), supporting the idea that emotional processing biases and attentional control resources can influence each other. However, using a self-report measure of attentional control reflects individuals' own perception of their control resources, while using a behavioural measure of attentional control or working memory capacity (e.g. the change detection task) provides a more 'objective' assessment and may therefore be better used to compare training related effects.

Our main outcome measure was the breathing focus task, which assesses the number of experienced negative intrusive thoughts before and after a period in which worrying thoughts are prompted. Overall there was an increase in negative intrusions across the period in which worrying thoughts were prompted, consistent with previous studies using this task

(Hayes et al., 2010; Hirsch et al., 2009). Additionally, we also observed an overall decrease in the number of experienced negative intrusive thoughts across the training period. However, training condition did not seem to influence this. We then tested how individual differences in training related changes in working memory capacity and interpretation bias related to changes in experienced negative intrusive thoughts. This allowed us to examine the effects of training induced changes in the underlying cognitive processes, taking into account inter-individual differences in training engagement or effectiveness. We showed that greater increases in positive interpretation bias, as measured with the scrambled sentence task, were related to an overall reduction in the experience of negative intrusive thoughts. Furthermore, a greater increase in working memory capacity, reflected by improved performance on the distractor trial type in the change detection task, was related to reduced reactivity of negative intrusions across the worry period. These findings show that a more benign interpretation bias and improved working memory can have beneficial effects in terms of the experience of negative intrusive thoughts, but it's important to note that this was dependent upon the level of improvement from training. It highlights that our existing training paradigms could be further improved to boost training related gains which exceed (small to moderate) gains obtained also through 'active' sham training.

The current findings show increased positive interpretative processing and working memory capacity could attenuate the experience of negative intrusive thoughts through different pathways. Having a more benign interpretation bias may generally reduce the experience of negative intrusive thoughts by decreasing the likelihood that external or internal cues activate threat representations that compete with task-related representations for attention (Hirsch & Mathews, 2012). If negative thoughts are less likely to intrude into awareness and develop into a worry episode, this will leave more attentional resources for the task at hand. At the same time, once negative thoughts intrude into awareness, improved

attentional control resources can attenuate worry by maintaining control over attention and facilitate redirection of attention to the task at hand or more benign thoughts (Berggren & Derakshan, 2013; Hirsch & Mathews, 2012).

Although we observed that the tendency to worry was influenced when considering individual differences in training related gains, no effect was found when comparing training conditions. This highlights the difference between examining effects of changes in underlying target processes (e.g. degree of change in working memory capacity) and examining effects of the tasks employed to modify these processes (e.g. adaptive working memory training vs. sham training) (Grafton et al., 2017; MacLeod & Grafton, 2016). The procedures used to modify target processes such as CBM-I and the adaptive dual n-back task may not be effective to the same extent in all individuals. We found that the degree of change in working memory capacity or positive interpretation bias had a small to moderate effect on the tendency to worry. This supports cognitive models of worry and anxiety positing that, in worry-prone individuals, negative emotion processing biases, impaired attentional control, and their interplay contribute to excessive worry (Berggren & Derakshan, 2013; Hirsch & Mathews, 2012). Psychological interventions targeting (prevention of) pathological worry may thus benefit from including procedures that facilitate benign interpretative processing and increase attentional control resources. However, our findings also point out that the existing procedures as methods to facilitate working memory and positive interpretation bias leave much room for improvement.

Future research should examine the factors influencing effectiveness of cognitive training (e.g. number of training sessions, using an adaptive component), longer-term effects of training, and for whom (e.g. certain symptom profiles) it works best. Especially if cognitive training is to be an ‘add-on’ component to intervention programmes or used as a preventive intervention, it is essential that such procedures are effective in causing a reliable

change in the underlying processes in vulnerable and clinical populations. To further test the clinical potential of cognitive training procedures it is important to perform double-blind randomized controlled trials in larger samples to increase statistical power. Moreover, future research could investigate whether combining working memory training with CBM-I is superior to receiving either training on its own. A recent study in high-worriers investigated the effects of combining a week of working memory training with mindfulness meditation practice, showing that especially this combination resulted in positive effects on self-reported worry (Course-Choi, Saville, & Derakshan, 2017). These initial findings are promising and suggest that cognitive training could work as a catalyst for more established clinical treatments. Furthermore, when aiming to use cognitive training as a preventive strategy it will be especially important to follow individuals over time to see if they develop clinical symptom levels (e.g. GAD) and to investigate at what stage in development it is most beneficial to intervene (e.g. childhood vs. later adolescence).

The current experimental study contributes to our understanding of the causal relationship between interpretation bias, attentional control, and the tendency to worry in a sample of worry-prone individuals. Our findings show that facilitating a more benign interpretation bias and improving working memory capacity can have moderate beneficial effects in terms of worry, but highlight that transfer-related gains from existing training procedures can depend on improvement levels during training. This suggests there is room for improving the effectiveness of our existing training procedures which are not necessarily superior to active control training. Furthering our knowledge of the cognitive mechanisms underlying pathological worry and developing sophisticated training interventions that target these cognitive processes will benefit treatment for a range of emotional disorders given the transdiagnostic nature of worry.

### Acknowledgements

This research was funded by the European Research Council (ERC) under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC grant agreement no: [324176] to EF. Funding sources were not involved in study design, data collection, analysis and interpretation of data, writing of the report, nor in the decision making to submit the article for publication.

We would like to thank Dr. Anne-Wil Kruijt and Dr. Janna Vrijzen for their assistance in the development of some of the tasks.

A.S., M.G., N.D., C.H., E.B., and E.F. developed the study concept and contributed to the study design. Data collection was performed by M.G., J.S., C.B., and A.T-McC. M.G. performed the data analysis and interpretation under the supervision of N.D., C.H., and E.F. M.G. drafted the paper, and A.S., J.S., C.B., A.T-McC, N.D., C.H., E.B., and E.F. provided critical revisions. All authors approved the final version of the paper for submission. The authors declare no conflict of interest.

C.H. receives salary support from the National Institute for Health Research (NIHR), Mental Health Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King's College London. The views expressed in this article are those of the authors and not necessarily those of Kings College London, NIHR or the Department of Health.

## References

- American Psychiatric Association, A. P. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5* (5th ed.). Washington, D.C.: American Psychiatric Association.
- Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin & Review*, 22, 366–377. <http://doi.org/10.3758/s13423-014-0699-x>
- Beck, A.T., Steer, R.A., Brown, G. K. (1996). *BDI-II manual*. San Antonio, TX: The Psychological Corporation.
- Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety : Why you see them and why you don ' t. *Biological Psychology*, 92(3), 440–446. <http://doi.org/10.1016/j.biopsycho.2012.03.007>
- Borkovec, T. D., Robinson, E., Pruzinsky, T., & DePree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy*, 21(1), 9–16. [http://doi.org/10.1016/0005-7967\(83\)90121-3](http://doi.org/10.1016/0005-7967(83)90121-3)
- Corbetta, M., & Shulman, G. L. (2002). Control of Goal-Directed and Stimulus-Driven Attention in the Brain. *Nature Reviews Neuroscience*, 3(3), 215–229. <http://doi.org/10.1038/nrn755>
- Course-Choi, J., Saville, H., & Derakshan, N. (2017). The effects of adaptive working memory training and mindfulness meditation training on processing efficiency and worry in high worriers. *Behaviour Research and Therapy*, 89, 1–13. <http://doi.org/10.1016/j.brat.2016.11.002>
- Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, 111(2), 225–236. <http://doi.org/10.1037/0021-843X.111.2.225>

- Ehring, T., Zetsche, U., Weidacker, K., Wahl, K., Sch??nfeld, S., & Ehlers, A. (2011). The Perseverative Thinking Questionnaire (PTQ): Validation of a content-independent measure of repetitive negative thinking. *Journal of Behavior Therapy and Experimental Psychiatry*, 42(2), 225–232. <http://doi.org/10.1016/j.jbtep.2010.12.003>
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and Cognitive Performance : Attentional Control Theory. *Emotion*, 7(2), 336–353. <http://doi.org/10.1037/1528-3542.7.2.336>
- Eysenck, M. W., Mogg, K., May, J., Richards, A., & Mathews, A. (1991). Bias in Interpretation of Ambiguous Sentences Related to Threat in Anxiety, 100(2), 144–150.
- Fox, E., Dutton, K., Yates, A., Georgiou, G. a., & Mouchlianitis, E. (2015). Attentional Control and Suppressing Negative Thought Intrusions in Pathological Worry. *Clinical Psychological Science*, 3(4), 593–606. <http://doi.org/10.1177/2167702615575878>
- Grafton, B., MacLeod, C., Rudaizky, D., Holmes, E., Salemink, E., Fox, E., & Notebaert, L. (2017). Confusing procedures with process when appraising the impact of cognitive bias modification (CBM) on emotional vulnerability: A response to Cristea et al. (2015). *British Journal of Psychology*.
- Grey, S., & Mathews, a. (2000). Effects of training on interpretation of emotional ambiguity. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, 53(4), 1143–1162. <http://doi.org/10.1080/713755937>
- Hayes, S., Hirsch, C. R., Krebs, G., & Mathews, A. (2010). Behaviour Research and Therapy The effects of modifying interpretation bias on worry in generalized anxiety disorder. *Behaviour Research and Therapy*, 48(3), 171–178. <http://doi.org/10.1016/j.brat.2009.10.006>
- Hirsch, C. R., Hayes, S., & Mathews, A. (2009). Looking on the bright side: accessing benign meanings reduces worry. *Journal of Abnormal Psychology*, 118(1), 44–54.

<http://doi.org/10.1037/a0013473>

- Hirsch, C. R., & Mathews, A. (2012). A cognitive model of pathological worry. *Behaviour Research and Therapy*, 50(10), 636–646. <http://doi.org/10.1016/j.brat.2012.06.007>
- Hirsch, C. R., Meeten, F., Krah, C., & Reeder, C. (2016). Resolving Ambiguity in Emotional Disorders : The Nature and Role of Interpretation Biases. *Annual Review of Clinical Psychology*, 12, 281–305. <http://doi.org/10.1146/annurev-clinpsy-021815-093436>
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *PNAS*, 105(19), 6829–6833. <http://doi.org/10.1073/pnas.0801268105>
- Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, 14(7), 317–324. <http://doi.org/10.1016/j.tics.2010.05.002>
- Koster, E. H. W., Hoorelbeke, K., Onraedt, T., Owens, M., & Derakshan, N. (2017). Cognitive control interventions for depression : A systematic review of findings from training studies. *Clinical Psychology Review*, 53, 79–92. <http://doi.org/10.1016/j.cpr.2017.02.002>
- MacLeod, C., & Grafton, B. (2016). Anxiety-linked attentional bias and its modification: Illustrating the importance of distinguishing processes and procedures in experimental psychopathology research. *Behaviour Research and Therapy*, 86, 68–86. <http://doi.org/10.1016/j.brat.2016.07.005>
- Mathews, A., & Mackintosh, B. (2000). Induced emotional interpretation bias and anxiety. *Journal of Abnormal Psychology*, 109(4), 602–615. <http://doi.org/10.1037/0021-843X.109.4.602>
- Mathews, A., & MacLeod, C. (2005). Cognitive vulnerability to emotional disorders. *Annual Review of Clinical Psychology*, 1(1), 167–195. <http://doi.org/10.1146/annurev.clinpsy.1.102803.143916>



- Mccabe, D. P., Roediger III, H. L., Mcdaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The Relationship Between Working Memory Capacity and Executive Functioning: Evidence for a Common Executive Attention Construct. *Neuropsychology*, 24(2), 222–243. <http://doi.org/10.1037/a0017619>
- Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working Memory Training Does Not Improve Performance on Measures of Intelligence or Other Measures of “Far Transfer”: Evidence from a Meta-Analytic Review. *Perspectives on Psychological Science*, 11(4), 512–534. <http://doi.org/10.3837/tiis.0000.00.000>
- Menne-lothmann, C., Viechtbauer, W., Hohn, P., Kasanova, Z., Haller, S. P., Drukker, M., ... Lau, J. Y. F. (2014). How to Boost Positive Interpretations ? A Meta-Analysis of the Effectiveness of Cognitive Bias Modification for Interpretation. *PLoS ONE*, 9(6), 1–26. <http://doi.org/10.1371/journal.pone.0100925>
- Menne-Lothmann, C., Viechtbauer, W., Hohn, P., Kasanova, Z., Haller, S. P., Drukker, M., ... Lau, J. Y. F. (2014). How to Boost Positive Interpretations ? A Meta-Analysis of the Effectiveness of Cognitive Bias Modification for Interpretation. *PLoS ONE*, 9(6), 1–26. <http://doi.org/10.1371/journal.pone.0100925>
- Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the penn state worry questionnaire. *Behaviour Research and Therapy*, 28(6), 487–495. [http://doi.org/10.1016/0005-7967\(90\)90135-6](http://doi.org/10.1016/0005-7967(90)90135-6)
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, a H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: a latent variable analysis. *Cognitive Psychology*, 41(1), 49–100. <http://doi.org/10.1006/cogp.1999.0734>
- Mohr, D. C., Spring, B., Freedland, K. E., Beckner, V., Arean, P., Hollon, S. D., ... Kaplan, R. (2009). The selection and design of control conditions for randomized controlled

- trials of psychological interventions. *Psychotherapy and Psychosomatics*, 78(5), 275–284. <http://doi.org/10.1159/000228248>
- Molina, S., & Borkovec, T. D. (1994). The Penn State Worry Questionnaire: Psychometric properties and associated characteristics. In G. C. L. Davey & F. Tallis (Eds.), *Worrying: Perspectives on theory, assessment, and treatment* (pp. 265–283). Oxford, England: Wiley.
- Moran, T. P. (2016). Anxiety and Working Memory Capacity: A Meta-Analysis and Narrative Review. *Psychological Bulletin*, 142(5), 831–864. <http://doi.org/10.1037/bul0000051>
- Newman, M. G., Zuellig, A. R., Kachin, K. E., Constantino, M. J., Przeworski, A., Erickson, T., & Cashman-McGrath, L. (2002). Preliminary reliability and validity of the generalized anxiety disorder questionnaire-IV: A revised self-report diagnostic measure of generalized anxiety disorder. *Behavior Therapy*, 33(2), 215–233. [http://doi.org/10.1016/S0005-7894\(02\)80026-0](http://doi.org/10.1016/S0005-7894(02)80026-0)
- Owens, M., Derakshan, N., & Richards, A. (2015). Trait Susceptibility to Worry Modulates the Effects of Cognitive Load on Cognitive Control : An ERP Study. *Emotion*, 15(5), 544–549. <http://doi.org/http://dx.doi.org/10.1037/emo0000052>
- Owens, M., Koster, E. H. W., & Derakshan, N. (2013). Improving attention control in dysphoria through cognitive training: Transfer effects on working memory capacity and filtering efficiency. *Psychophysiology*, 50(3), 297–307. <http://doi.org/10.1111/psyp.12010>
- Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics*, 44(4), 369–378. <http://doi.org/10.3758/BF03210419>
- Ruscio, A. M., & Borkovec, T. D. (2004). Experience and appraisal of worry among high worriers with and without generalized anxiety disorder. *Behaviour Research and*

- Therapy*, 42(12), 1469–1482. <http://doi.org/10.1016/j.brat.2003.10.007>
- Sari, B. A., Koster, E. H. W., & Derakshan, N. (2016). The effects of active worrying on working memory capacity. *Cognition and Emotion*, 1–9.  
<http://doi.org/10.1080/02699931.2016.1170668>
- Sari, B. A., Koster, E. H. W., Pourtois, G., & Derakshan, N. (2016). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioral and electrophysiological measures. *Biological Psychology*, 121, 203–212.  
<http://doi.org/10.1016/j.biopsycho.2015.09.008>
- Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., & Dalgleish, T. (2013). Training the emotional brain: Improving affective control through emotional working memory training. *Annals of Internal Medicine*, 158(6), 5301–5311.  
<http://doi.org/10.1523/JNEUROSCI.2593-12.2013>
- Shipstead, Z., Lindsey, D. R. B., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity: Primary memory, secondary memory, and attention control. *Journal of Memory and Language*, 72(1), 116–141.  
<http://doi.org/10.1016/j.jml.2014.01.004>
- Sibrava, N. J., & Borkovec, T. D. (2006). The cognitive avoidance theory of worry. In G. C. L. Davey & A. Wells (Eds.), *Worry and its Psychological Disorders: Theory, Assessment and Treatment* (pp. 217–237). Hoboken: Wiley Publishing.  
<http://doi.org/http://dx.doi.org/10.1002/9780470713143.ch14>
- Spielberger, C.D., Gorsuch, R.L., Lushene, R., Vagg, P.R., & Jacobs, G. A. (1983). *Manual for the state-trait anxiety inventory*. Palo Alto (CA): Consulting Psychologists Press.
- Stout, D. M., Shackman, A. J., Johnson, J. S., & Larson, C. L. (2015). Worry is associated with impaired gating of threat From working memory. *Emotion*, 15(1), 6–11.  
<http://doi.org/10.1037/emo0000015>

- Tallis, F., Davey, G. C. L., & Bond, A. (1994). The Worry Domains Questionnaire. In G. C. L. Davey; F. Tallis (Ed.), *Worrying: Perspectives on theory, assessment, and treatment* (pp. 285–297). New York: Wiley.
- Vogel, E. K., Mccollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature*, 438(7067), 500–503. <http://doi.org/Doi 10.1038/Nature04171>
- Wenzlaff, R. M., & Bates, D. E. (1998). Unmasking a Cognitive Vulnerability to Depression : How Lapses in Mental Control Reveal Depressive Thinking, 75(6), 1559–1571.