A Randomised Controlled Trial Investigating the Benefits of Adaptive Working Memory Training for Working Memory Capacity and Attentional Control in High Worriers

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Abstract

The process of worry has been associated with reductions in working memory capacity and availability of resources necessary for efficient attentional control. This, in turn, can lead to escalating worry. Recent investigations into working memory training have shown improvements in attentional control and cognitive performance in high trait-anxious individuals and individuals with sub-clinical depression. The current randomised controlled trial investigated the effects of 15 days of adaptive *n*-back working memory training, or an active control task, on working memory capacity, attentional control and worry in a sample of high worriers. Pre-training, post-training and one-month follow-up measures of working memory capacity were assessed using a Change Detection task, while a Flanker task was used to assess attentional control. A breathing focus task was used as a behavioural measure of worry in addition to a number of self-report assessments of worry and anxiety. Overall there was no difference between the active training and the active control condition with both groups demonstrating similar improvements in working memory capacity and worry, post-training and at follow-up. However, training-related improvements on the *n*-back task were associated with gains in working memory capacity and reductions in worry symptoms in the active training condition. These results highlight the need for further research investigating the role of individual differences in working memory training.

Keywords: Working Memory Training; Worry; Attentional Control

Introduction

Worry is defined as “the repeated experience of apparently uncontrollable thoughts regarding future negative events” (Hayes, Hirsch, & Mathews, 2008, p. 3). It occurs on a continuum, with generalised anxiety disorder (GAD) falling at the more severe end (American Psychiatric Association, 2013). GAD affects an estimated 4.4% of people in England (McManus, Meltzer, Brugha, Bebbington, & Jenkins, 2009), while 6.2% of the adult population of the United States of America will also experience GAD during their lifetime (Kessler, Petukhova, Sampson, Zaslavsky, & Wittchen, 2012). This results in severe disability or limitations to usual activities for 42% of sufferers (Sanderson & Andrews, 2002). Within the United Kingdom, treatment guidelines recommend Cognitive Behavioural Therapy or selective serotonin reuptake inhibitors for individuals with marked functional impairment as a result of significant worry (National Institute for Health and Care Excellence, 2011).

Worry can have a disruptive influence on major cognitive functions, including working memory, which play a crucial role in every day functioning. It has been suggested that worry acts as an internal distracter, attracting attention away from a current task, and thus reducing the capacity for attentional control (Hirsch & Mathews, 2012). Working memory capacity (WMC), a concept that is closely related to attentional control (Shipstead, Lindsey, Marshall, & Engle, 2014), reflects “the *efficacy* by which goal relevant information is attended, stored, and maintained while task irrelevant information is suppressed” (Sari, Koster, & Derakhshan, 2016, p2.). When WMC is reduced, attentional control is also affected, since an individual has fewer resources accessible for voluntary, top-down control of attention towards current task demands (Hirsch & Mathews, 2012). For instance, trait vulnerability to worry (Owens, Derakhshan & Richards, 2015) as well as an episode of active worrying (Sari, Koster & Derakhshan, 2016) can reduce WMC, affecting major executive

Abbreviations: CBT = Cognitive Behavioural Therapy; FMPS = Frost Multidimensional Perfectionism Scale; GAD = Generalised Anxiety Disorder; MINI = Mini International Neuropsychiatric Interview; NART = National Adult Reading Test; PSWQ = Penn State Worry Questionnaire; STAI-TA = Spielberger Trait Anxiety Inventory; WDQ = Worry Domains Questionnaire; WMC = working memory capacity; WMT = working memory training functions such as inhibition of irrelevant material, leading to the inefficient processing of relevant information.

In support of this perspective, worry-prone individuals have been shown to perform less well on tasks requiring attentional control. Stout, Shackman, Johnson and Larson (2015), for instance, found that individual differences in subjective worry are associated with difficulties gating threat distracters from working memory during a change detection task. Moreover, once threat-related information is in working memory, it biases attention, even if the threat is no longer present. This mechanism produces a vicious cycle leading to escalating levels of worry. Further evidence comes from the observation that individuals with (pre-existing) limited attentional control resources, as reported on a self-report scale, are particularly vulnerable to bias towards threat, as indicated by difficulties disengaging from threatening information during a simple detection task (Derryberry and Reed, 2002). Moreover, Stefanopoulou, Hirsch, Hayes, Adlam and Coker (2014) invited participants to complete a random key-pressing task while thinking about a worrisome event and observed that worry consumed more attentional control resources in individuals with GAD than in control participants, as indicated by a decrease in the proportion of random key presses by participants with GAD (but not controls) when thinking about a worrying event, compared to a positive event. Stefanopoulou et al. also demonstrated that people with GAD had greater difficulty than controls in sustaining attention when demands on attentional control were increased during a *n*-back task. These results largely replicated those found by Hayes, Hirsch, & Mathews (2008) who had also used a random key-press task to demonstrate that high worriers show more restricted WMC, and hence fewer attentional resources, when thinking about a current worry than when thinking about a positive topic, an effect not found in low worriers. Similarly, Sari et al. (2016) found that compared to a non-worry control condition, students undergoing a period of active worry demonstrated impaired WMC, and this effect was mediated by self-reported worry.

A recent meta-analysis (Moran, 2016) has confirmed the consistent link between anxiety or worry and limitations in WMC, and how the combination of high worry and low WMC, appears to reduce the cognitive resources available for attentional control. This body of work leads to the suggestion that it may be valuable to train WMC in high worriers. By training WMC, the efficiency of attentional control is likely to increase, which should in turn reduce worry, as there will be more mental resources available to exert cognitive control over whether negative thoughts attract attention.

One issue associated with many of the studies discussed above is the subjective nature of the measurements used to assess worry. Such methods are often susceptible to bias themselves and therefore it is useful to also obtain a more objective measure of worry. A widely-used method was introduced by Borkovec, Robinson, Pruzinsky and DePree (1983) that involves an assessment of participants' ability to focus on their breathing before and after a time-period of worrying. An adaptation of this task was used by Fox, Dutton, Yeats, Georgiou and Mouchlianitis (2015) to assess the effectiveness of a cognitive training procedure designed to improve attentional control on the reduction of worry. Although the cognitive training procedure (based on the flanker task) was largely ineffective, they found that improvements in attentional control were associated with participants' ability to suppress worry-related thought intrusions during a breathing-focus task similar to that used by Borkevec et al. Such findings highlight the value of including both subjective and objective measures of worry during the assessment of interventions targeting a reduction in worry.

A growing body of research is investigating whether it is possible to train WMC. For example, Jaeggi, Buschkuehl, Jonides and Perrig (2008) successfully used an adaptive dual *n*-back task to train the WMC of healthy participants. In the dual *n*-back task, participants are required to make a decision about whether paired visual and auditory stimuli match those presented *n* trials back, with difficulty increasing up to the 4-back level. Task difficulty is adjusted relative to task performance, thus providing adaptive training, and resulting in load on working memory gradually increasing over time. Jaeggi et al. found that, compared to a non-adaptive control condition, as few as 17 days of training using the dual *n*-back task led to improvements in both WMC and fluid intelligence, as measured by the Bochumer Matrizen-Test. Importantly, this test was entirely unrelated to the *n*-back task, indicating a transfer of training effects. Despite findings such as that by Jaeggi et al., there is still much debate about the effectiveness of working memory training. Indeed, in a meta-analytic review of 87 publications reporting on the impact of WMT on a variety of cognitive functions, Melby-Lervåg, Redick and Hulme (2016) concluded that, while there was evidence for improvements on near transfer tasks (e.g., verbal and visuospatial working memory), there was no evidence for far-transfer to other cognitive abilities such as reading comprehension, mathematical ability, or general measures of verbal or nonverbal ability. This extensive review did not, however, consider the potential benefits of WMT in emotionally vulnerable populations.

There has been much recent debate about the potential benefits of adaptive working memory training (WMT) in emotionally vulnerable populations, such as those with depression or anxiety (see Keshavan, Vinogradov, Rumsey, Sherrill, & Wagner, 2014; Koster et al, 2017; Motter et al, 2016 for discussion). To illustrate, Owens, Koster and Derakhshan (2013) found that, compared to a non-adaptive training control group using a 1-back version of WMT, eight days of adaptive working memory training on the dual *n*-back task led to training related gains in WMC, as measured by a change-detection task and these gains correlated with improvements in inhibitory function as measured by electroencephalography (EEG). In a follow-up study, high trait anxious participants were randomly assigned to 15 sessions of adaptive dual *n*-back or non-adaptive dual 1-back training (Sari, Koster, Pourtois and Derakshan, 2016). The three weeks of adaptive training led to significant improvements in attentional control, as measured by a Flanker task and resting state EEG, and these gains were associated with a reduction in trait anxiety. Furthermore, Sari et al. (2016) observed that the level of improvement on the *n*-back task was significantly associated with reductions in anxiety symptomology. This indicates that the degree of engagement with the training task may predict the extent to which training leads to far-transfer improvements on emotional domains, such as anxiety.

Hadwin and Richards (2016) investigated the effects of WMT in children who reported elevated anxiety and reduced attentional control. Elevated anxiety was indicated by a score above the average population norm on the Spence Children's Anxiety Scale (Spence, 1998), while reduced attentional control was signified by a below median score on the attention subscale of the Early Adolescent Temperament Questionnaire Revised (Ellis & Rothbart, 2001). Thirty-six participants aged eleven-to-fourteen years were randomly allocated to an adaptive WMT group or an active cognitive behavioural therapy (CBT) control group. Children in the adaptive group completed twenty-five sessions of WMT, over a period of five weeks, while the control group involved ten bi-weekly one-hour sessions of group CBT, also over a period of five weeks. Hadwin and Richards found that both interventions were equally effective at reducing anxiety symptoms, increasing inhibitory control and reducing attentional biases to threat. These improvements were maintained at three-month follow-up. Since WMT does not require regular sessions with a therapist, it has the potential to be a cost-effective alternative, or adjunct to CBT, suggestion that WMT may be a plausible low-level intervention for protecting against the development of clinical anxiety in at risk individuals.[1]

Course-Choi, Saville and Derakhshan (2017) compared seven days of dual *n*-back training with dual *n*-back training in combination with mindfulness meditation practice and separate mindfulness meditation practice. A reduction in self-reported worry was observed in the *n*-back training-only and mindfulness-only groups, with the greatest decrease occurring in the combined group. Furthermore, WMC, as measured by a Change Detection Task, improved in all three groups as a result of training. This study highlights the potential of WMT when used in conjunction with more well-established psychological interventions. In contrast to reviews finding little evidence for "far transfer" effects of WMT in non-clinical populations (e.g. Melby-Lervåg et al., 2016), there is growing evidence that computerised cognitive training might be of benefit for clinical populations. A systematic review of computerised cognitive interventions for individuals with major depressive disorder reported moderate-to-large effect sizes for multiple cognitive domains, including attention and working memory along with small-to-moderate improvements in symptom severity (Motter et al, 2016). Similarly, a recent systematic review by Koster, Hoorelbeke, Onraedt and Derakshan (2017) found that cognitive control training interventions for depression, such as the *n*-back task, may have the greatest impact for those who are most cognitively impaired and/or most engaged with the training intervention.

Given the evidence that, compared to the general population, the WMC and attentional control of high worriers are particularly impeded, it may be that WMT is of particular value for this population, as there is greater scope for gain in these domains. There is therefore an urgent need to systematically and rigorously evaluate whether or not WMT is an effective intervention for individual who are worry-prone.

Objectives

Given the hypothesized role of working memory difficulties in the maintenance of worry, WMT may have some benefits for reducing worry in high-worriers. Since significant levels of worry have a negative impact on day-to-day activity involving cognitive functions (Sanderson & Andrews, 2002) even a small improvement may have a significant impact on an individual's wellbeing. The current study investigated the effects of an adaptive visual *n*-back WMT on the ability to control worry in a sample of high worriers. The effects of training were assessed immediately post-training and at a four-week follow-up. Training effects of WMT were assessed using a Change Detection task, which is a widely-used measure of WMC (Vogel, McCollough, & Machizawa, 2005). The effect of WMT on inhibitory control was assessed using a modified version of the Flanker task (Erikson & Erikson, 1974), which assesses participants' ability to focus on a specific stimulus, while inhibiting attention to distractor stimuli. The effects of WMT on self-reported symptoms of trait anxiety and worry were assessed using the Spielberger Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), the Worry Domains Questionnaire (Tallis, Eysenck, & Mathews, 1992), and the Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990). In order to minimise the effects of response bias and provide a more objective, behavioural, measure of worry, this study also included a breathing focus task based on the protocol of Hirsch, Hayes, & Mathews (2009), which itself was an adaptation of the task introduced by Borkovec et al. (1983). This was a novel aspect of the current study, which effectively provides a far-transfer measure of participants' worry symptoms.

We predicted that, compared to an active control group, adaptive visual *n*-back WMT would improve WMC, as measured by a Change Detection task, as well as improve performance on the flanker task, and reduce worry symptomatology. We also expected to replicate Sari et al.'s (2015) observation that training-related gains were associated with reduced symptomology. We therefore predicted an association between improvement on the training task and reductions in worry and anxiety on subjective as well as objective (behavioural) measures.

Methods

Study Design

Participants were randomised to complete either 15 days of online adaptive visual *n*-back WMT training or 15 days of non-adaptive visual 1-back WMT. Participants completed self-report and objective measures at baseline, immediately post-training, and at a four-week follow-up. The study was reviewed and approved by the University of Oxford's Central University Research Ethics Committee (Ref: MSD-IDREC-C1-2014-215).

Participants

Participants were high worriers who scored 56 or above on the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990). This cut-off was chosen as it is more than one standard deviation above the mean for a general non-clinical sample (van Rijsoort, Emmelkamp, & Vervaeke, 1999). Participants were invited for PSWQ screening if they were over 18 years of age, had normal or corrected-to-normal hearing and vision and were fluent in English. Participants were excluded if they had a lifetime history of bipolar disorder or psychosis, participated in other WMT studies, illicit drug use, or were on current psychotropic medication use.

The Mini-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) was carried out via telephone to ensure participants who scored ≥56 on the PSWQ did not have a history of psychosis or bipolar disorder, and to collect demographic information (see Table 1 for a summary of demographic characteristics). Thirty-nine individuals in total were excluded for not meeting PSWQ criteria, while a further two were excluded following MINI screening (both were currently taking psychotropic medication).

Table 1. Descriptive statistics for sample characteristics.

Variables	Training (n = 20)	Control (n = 21)
Mean age (years)	29.20 (SD = 11.75)	29.90 (SD = 9.76)
No. female (%)	16 (80.0)	16 (76.2)
No. Caucasian (%)	16 (80.0)	11 (52.4)
DSM-IV diagnosis: GAD (%)	9 (45.0)	9 (42.9)
DSM-IV diagnosis: ≥ 1 anxiety disorder (%)	12 (60.0)	13 (61.9)
PSWQ screening score	66.08 (SD = 5.90)	67.38 (SD = 5.55)

Note: SD, Standard Deviation; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition; GAD, Generalised Anxiety Disorder; PSWQ, Penn State Worry Questionnaire.

Power calculations based on previous research using adaptive *n*-back WMT (Owens et al., 2013; Sari et al., 2015) and statistical analysis using mixed-model analysis of variance (ANOVA) suggested that samples sizes of 19 per group would achieve a medium effect size of at least 0.50 at an $\propto$-level of 0.05. A community sample of 47 high worriers was recruited via posters in public spaces and advertisements in local media and social media. Participants were randomly assigned to the adaptive *n*-back condition (n = 23) or non-adaptive 1-back active control condition (n = 24) using a random sequence generator. A total of six participants (three in each group) were not included in the final data analyses due to attrition between the initial assessment and post-training assessment (see Figure 1 for flow of participants through the trial).

Outcome Measures

Baseline demographic measures. The National Adult Reading Test (NART) was used to assess verbal ability. It is a test of reading consisting of 50 single words of graded difficulty (Nelson & O'Connell, 1982) and has high test-retest reliability, inter-rater reliability and internal consistency (Crawford, 1992). It was included as a baseline comparator between groups because verbal ability is believed to be associated with both WM ability and task performance (Holmes, Gathercole, & Dunning, 2009). The Frost Multidimensional Perfectionism Scale (FMPS; Frost, Marten, Lahart, & Rosenblate, 1990) was used to compare baseline levels of perfectionism in the two groups. This was used because, based on anecdotal evidence from other researchers who have conducted WMT studies, it was believed that perfectionism may affect participant engagement with WMT, which is known to be associated with training-related gains (e.g. Sari et al., in press). As such, it was predicted that higher perfectionism at baseline would be associated with greater training-related gains. The FMPS is a 35-item measure with an internal reliability of 0.90 and good construct validity (Frost et al.).

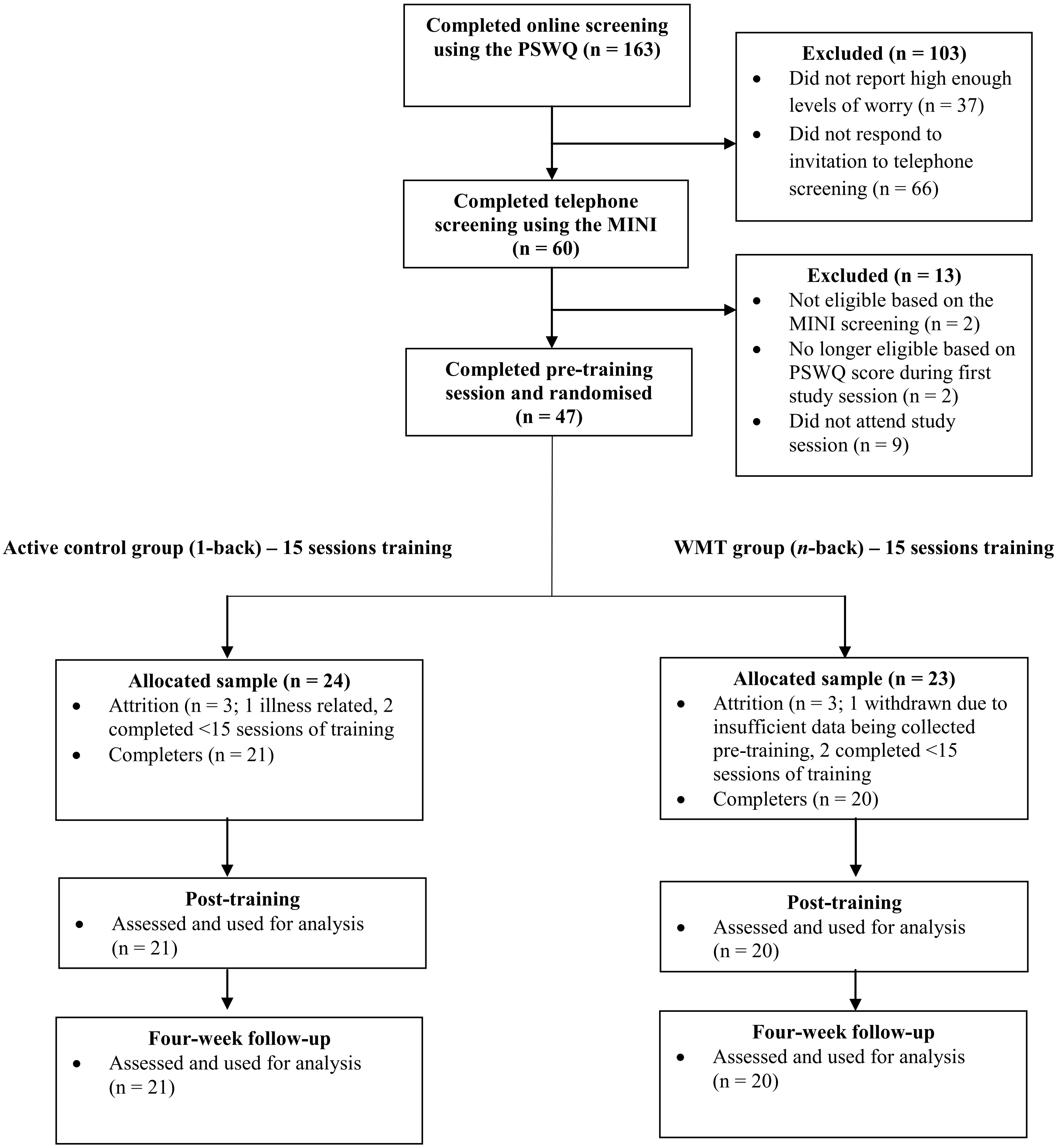

Figure 1. Flow of participants through the trial. *Note:* PSWQ, Penn State Worry Questionnaire; MINI, The Mini-International Neuropsychiatric Interview.

Objective measures. The Change Detection task (CDT) was used as a measure of effects of training on visuospatial working memory. The version was that used by Owens et al. (2013), developed from Vogel et al. (2005). Participants were required to hold in memory two or four red rectangles, while ignoring blue rectangles and decide whether or not the orientation of red rectangles changed across two time points. Stimuli were presented on a black background and consisted of arrays of two-to-four rectangles (0.64 degrees (°) × 1.21°) at a distance of at least 2° from each other. They were displayed in random positions within 4° × 7.2° rectangular regions, the centres of which were 3° from a white central fixation cross. Rectangles were either red (target stimuli) or blue (distractor stimuli) and were randomly oriented in one of four ways (left 45°, right 45°, horizontal or vertical).

The task had three conditions: a two-item condition, a four-item condition or a distractor condition (two blue rectangles and two red rectangles). Participants were instructed to remember the orientations of the red rectangles presented in the memory array. Each trial started with a 700ms fixation cross in the centre of the screen, with a white arrow pointing either to the left or right side of the screen, which cued participants to the side of the screen to which they should attend. Following this, stimuli from one of the three conditions were presented on both sides of the fixation cross for 100ms. This was followed by a 900ms retention period, after which rectangles were redisplayed for 2000ms (test array), during which time participants were instructed to specify whether the orientation of one of the memorised two or four red rectangles had changed. The size of the array (two, four or distractor); whether or not there was a change and the direction of the initial arrow were randomised across the experiment and each were displayed an equal number of times. Participants completed a practice period of 24 trials (8 trials per condition), followed by four experimental blocks of forty-eight trials.

A modification of the Flanker task (Erikson & Erikson, 1974) was used to assess inhibition. In this task participants were instructed to ignore distractor stimuli, while attending to a simple X/N letter classification task. Each trial started with a 1000ms fixation cross followed by a search array (e.g. six dots on a line) and in one of the positions the dot was replaced by a letter, either X or N. Participants were instructed to respond to this letter by pressing one of two response buttons, while ignoring an additional task-irrelevant letter appearing outside the search array in the periphery.

Participants performed four blocks of ninety-six trials. Each block was counterbalanced, controlling for: the number of possible target locations in the search array (six); target identity (X or N); distractor location (top or bottom periphery) and distractor identity (X or N). The task therefore had 48 possible trials, and each ran through twice per block. The search array was presented for 100ms, followed by blank window of 1900ms during which participants responded to the target letter.

A breathing focus task was used as an objective measure of worry (Hirsch et al., 2009). The task involved three phases, each lasting five minutes: a pre-worry breathing focus period; an instructed worry period and a post-worry breathing focus period. During the five-minute breathing focus task, a computer-generated tone sounded at random 20-30 second intervals. At each tone participants were instructed to report whether their attention was focused on their breathing or on an intrusive thought, include a brief description and indicate the valance of the thought content (i.e. positive, negative or neutral).

Following the five-minute breathing focus period, there was an instructed worry period that required participants to worry about a topic of personal worry. This was discussed briefly with the experimenter to make sure it was a worry (e.g. about a potentially negative future occurrence). Participants were then left to silently worry about the topic for five minutes. This was immediately followed by the second breathing focus period. The main dependent variables for this task were the number of negative intrusions in the two separate five-minute breathing focus periods and the change in number of negative intrusions (reactivity) between the two breathing periods. Participants were also invited to rated their anxiety on a 0-100mm visual analogue scale after each breathing period. Hirsch et al. (2009) found inter-rater reliabilities for assessment of the number of negative intrusions to be 84.3%, indicating this task to be a reliable and objective measure of worry. Support for the validity of the breathing focus task was provided Borkovec et al. (1983), who observed that worriers experienced more negative intrusions during a breathing period than non-worriers. Likewise, Hirsch, Mathews, Lequertier, Perman and Hayes (2013) who found that a group of individuals diagnosed with GAD had greater severity and frequency of negative intrusions during a five-minute breathing period, when compared to high worriers. Importantly, a significant difference was also observed between Worry Domains Questionnaire (Tallis et al., 1992) ratings for the two groups, with individuals with GAD scoring higher.

Self-report measures. Joormann and Stober (1997) highlighted how there are typically two forms of worry questionnaire. "Content-free" measures ask about clinical aspects of worry, such as excessiveness, duration and uncontrollability, while "content-based" measures generally measure non-pathological worry across typical worry domains. As such, both "content-free" and "content-based" measures of worry were included in the current study. The PSWQ (Meyer et al., 1990) is a 16-item "content-free" measure of worry, focusing specifically on aspects of clinically significant worry, in line with the main diagnostic criteria for GAD. The PSWQ has high construct validity (van Rijsoort et al., 1999), internal consistency (α = .94; Davey, 1993) and test-retest reliability (r = 0.92; van Rijsoort et al).

The Worry Domains Questionnaire (WDQ; Tallis et al., 1992) is a 30-item "content-based' measure of non-pathological worry which produces a global score across six domains:

relationships; lack of confidence; aimless future; work incompetence; financial; and socio-political. It has good test-retest (r = .85 over four weeks) reliability (Stober, 1998).

The Spielberger Trait Anxiety Inventory (STAI-TA; Spielberger et al., 1983) was used to measure trait anxiety. It is a 20-item self-report measure with high internal consistency (average α >.89), strong construct validity and an average test-retest reliability of r = .88 (Barnes, Harp, & Jung, 2002).

Working Memory Training

***n*-back training.** Training consisted of an adaptive visual *n*-back task. On each trial participants were presented with a single green square presented in any of eight locations in a 3 x 3 grid on a computer screen. Participants were instructed to make a decision (yes/no – button press) as to whether the current stimulus was in the same location as the stimulus presented *n* positions back. Square stimuli were presented for 500ms, followed by an inter-trial interval of 2500ms. The adaptive aspect of the task meant the level of *n*, and hence task difficulty, was increased (e.g. 2-back, 3-back or 4-back) or decreased based on performance. Daily training sessions consisted of 20 blocks of 20 + *n* trials. Each training session began with participant at the 1-back level and after each block the level of *n* increased if the participant had achieved 95% accuracy and decreased if accuracy was below 75%. Otherwise it remained unchanged (see Figure 2 for an example of a 1-back trial).

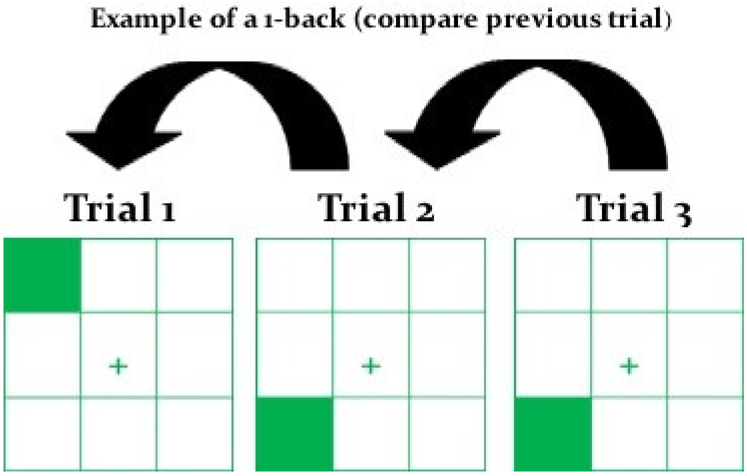

Figure 2. Example of a 1-back trial.

Control training. In the active control condition participants completed 20 blocks of 20 trials in each training session. However, all blocks remained at the 1-back level to ensure that the control group completed a non-adaptive version of the task.

Procedure

Participants were sent an information sheet and invited to complete an online PSWQ screening questionnaire if they were interested in taking part in the study. The MINI was completed over the telephone with participants who satisfied the inclusion criteria. Included participants then attended a pre-training session, during which informed consent was obtained. Participants completed the NART, FMPS, WDQ, PSWQ and STAI-TA, followed by the breathing focus, Change Detection and Flanker tasks. At the end of the pre-training session, each participant was randomly allocated to their training condition and completed a single practice block of the visual 1-back task.

Following the pre-training session, participants completed exactly fifteen days of approximately thirty minutes training on either the visual adaptive *n*-back or non-adaptive 1-back task, over a three-week period at home. Participants in both groups received daily emails from the experimenter to remind them to complete that day's training session and to thank them for completing the previous day's session. Participants were informed that they would be removed from the study if they completed more or less than 15 days of training.

Exactly three weeks after session one, and the day after their 15^{th} training day, participants attended a post-training session, during which they repeated all measures and tasks from the pre-training session, apart from the NART and FMPS. A follow-up session (session three) followed the same structure and was exactly four weeks after the post-training session. After the follow-up session, participants were debriefed and remunerated £150 plus travel expenses for their time.

Data Analysis

Data were analysed using SPSS 23.0. Independent samples *t*-tests were used to compare baseline characteristics between groups. Mixed model analyses of variance (ANOVA), with a between-factor of group (adaptive *n*-back, control) and within-subjects factor of time (pre-training, post-training, four-week follow-up) were conducted to assess the effects of WMT on CDT and flanker task performance, as well as on self-report and behavioural measures of worry and anxiety. The Pearson correlation coefficient was used to assess the association between training related gains and reductions in worry and anxiety.

Normality and outliers were assessed using histograms and box plots, as well as the Kolmogorov-Smirnov test. Further assumptions were assessed using Mauchly's test for sphericity and Levene's test for homogeneity of variance. Greenhouse-Geisser adjustments are reported where the assumption of sphericity was violated.

Change Detection task data for one participant (training group) was discarded from both the 4-item and distraction conditions, as the participant reported that they had got the response buttons the wrong way around during their first session. Data for two further participants was discarded, one in the 4-item condition (control group) and one in the distractor condition (training group) because their WMC was more than three interquartile ranges below the first quartile. Performance on the CDT was determined by calculation of WMC, using the commonly used formula (Pashler, 1988): K = S × (H – F)/(1 – F), where K is WMC, S is the set size of the array, H is the observed hit rate and F is the false alarm rate. Working memory capacity was estimated using K scores for the four-item condition. This aimed to eliminate the ceiling effects often observed in the two-item condition and floor effects often observed in the distractor condition (Lee, Cowan, Vogel, Valle-Inclan, & Hackley, 2010; Owens et al., 2013).

Consistent with Sari et al. (in press), performance on the Flanker task was measured using interference scores: the difference in response time between when the distractor and target stimuli were the same (compatible trials) and when they differed (incompatible trials). Flanker data for seven participants (3 = Control; 4 = Training) were discarded due to low accuracy rate (greater than three interquartile ranges below the first quartile) and high interference scores (greater than three interquartile ranges above the third quartile). Only response time data for correct trials were analysed.

Results

Sample Characteristics

Sample characteristics for the final sample are displayed in Table 1. This includes demographic characteristics, scores on the PSWQ screening and whether the participant satisfied formal diagnostic criteria for GAD, or any other anxiety disorder (GAD, phobia, social anxiety, panic disorder, agoraphobia or hypochondriasis), as assessed by the MINI. Income or socioeconomic status was not measured. There were no significant differences between control and training groups for the number of participants fulfilling diagnostic criteria for GAD, χ^2 (1, N = 41) < 1, *NS*., or at least one anxiety disorder, χ^2 (1, N = 41) < 1, *NS*. The two groups had similar age, $t(39) < 1$, *NS*., gender distribution, χ^2 (1, $N = 41$) < 1, *NS*., and ethnicity distribution, χ^2 (1, $N = 41$) = 3.48, $p = .10$. There was no significant difference between groups on PSWQ scores at screening $t(39) < 1$, *NS*.

Baseline Characteristics

As shown in Table 2, there were no significant baseline differences between the control and training groups on any of the outcome measures. Additionally, the baseline scores for the six participants who dropped-out of the study before completion of *n*-back training were compared to those who completed training. Baseline scores were equivalent for all measures apart from perfectionism, $U = 41$, $p = .007$, $r = .38$, PSWQ scores, $U = 52.50$, $p = .022$, $r = .33$, WDQ scores, $U = 47$, $p = .013$, $r = .35$ and STAI-TA scores, $U = 47.00$, $p = .015$, $r = .35$, with non-completers scoring lower on each of these measures at baseline.

Table 2. Comparison of baseline characteristics between groups.

Outcome Measure	**Training group Mean (SD)**	**Control group Mean (SD)**	**Statistic**	**Significance (*p*, 2-tailed)**	**Effect size (*d*)**
Predicted VIQ (NART)	115.40 (5.42)	116.05 (6.60)	$t(39) = .34$	.67	.14
Perfectionism (FMPS)	89.35 (19.85)	94.95 (17.07)	$t(39) = .97$	.34	.30
Penn State Worry Questionnaire	68.30 (6.58)	67.86 (5.09)	$t(39) = .24$	.81	.076
Worry Domains Questionnaire	55.85 (18.67)	61.48 (13.83)	$t(39) = 1.10$	.28	.35
Trait Anxiety Inventory	54.40 (7.85)	56.00 (7.60)	$t(39) = .66$	.51	.22
Number of negative intrusions pre-worry (Breathing focus task)	2.00 (1.62)	2.05 (1.88)	$t(39) = .087$	.93	.028
Working Memory Capacity (CDT; 4-item condition)	2.06 (0.76)	2.32 (0.62)	$t(37) = 1.17$	.25	.39
Working Memory Capacity (CDT; distractor condition)	1.42 (0.44)	1.55 (0.28)	$t(36) = 1.11$	.28	.43

Interference score (Flanker)	24.63 (18.41)	39.56 (36.36)	$t(32) = 1.48$	.15	.52

Note: SD, standard deviation; VIQ, verbal intelligence quotient; NART, National Adult Reading Test; FMPS, Frost Multidimensional Perfectionism Scale; CDT, Change Detection Task.

Performance on the *n*-back Tasks

Control group. Accuracy (hit rate minus false alarm rate) was averaged to assess control group performance across the 15 sessions. The control group showed 95.44% accuracy (SD = 9.06%) overall, indicating good performances across sessions and their scores did not vary between the first 1-back session (M = 95.89%, SD = 8.55%) and the last 1-back session (M = 94.65%, SD = 11.04%), $t(20) = 1.22$, $p = .24$, $d = .55$. This indicates that participants in the control group maintained a good level of engagement throughout training.

Training group. Figure 3 shows mean *n*-back performance for the training group over the 15 training sessions. In line with previous research (i.e. Jaeggi et al., 2008; Owens et al., 2013), the first three blocks from each training session were excluded from analysis, with the remaining seventeen blocks being used to calculate the participants' level of training for that session. Participants demonstrated an improvement in working memory as a result of training, as determined by significant improvements in performance from the first two days of training ($M = 2.54$, $SD = .63$) to the last two days ($M = 3.28$, $SD = .93$), $t(19) = 4.50$, $p < .001$, $d = 1.01$.

As well as measuring training improvement by calculating the difference between the mean *n*-back level for the first and last two training sessions, training improvement was also quantified by calculating the slope of a linear regression model, using the mean *n*-back level each day of training for each participant. The slope of improvement was significantly different from zero ($M = 0.053$, $SD = 0.055$), $t(19) = 4.28$, $p < .001$, $d = 0.96$, 95% CI [0.42, 1.48].

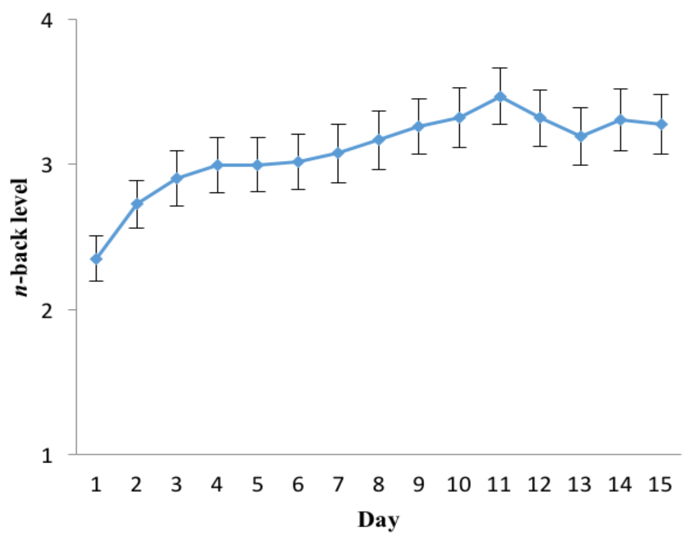

Figure 3. Mean *n*-back level across training. Lines indicate standard errors.

Objective Measures

Change detection task. Mean WMC for both groups are shown in Table 3[2]. In the four-item condition, a mixed model ANOVA with a between-subjects factor of group and within-subjects factor of time indicated a significance effect of time, $F(2, 74) = 8.67$, $p < .001$, $\eta_p^2 = .19$, 95% CI [.045, .328] with both groups demonstrating improved WMC over time. Bonferroni corrected post hoc tests showed that WMC was significantly higher post-training ($p = .006$) and at follow-up ($p = .004$) compared to pre-training. However, the main effect of group, $F(1, 37) = 0.43$, $p = .52$, $\eta_p^2 = .012$, or group × time interaction, $F(2, 37) = 2.29$, $p = .11$, $\eta_p^2 = .058$, were not significant.

Table 3. Training effects on objective and subjective self-report measures.

Outcome Measure	**Group**	**Pre-training Mean (SD)**	**Post-training Mean (SD)**	**Four-week follow-up Mean (SD)**
Working Memory Capacity (CDT – 4-item condition)	Training	2.06 (0.76)	2.53 (0.74)	2.43 (0.74)
	Control	2.32 (0.62)	2.44 (0.87)	2.68 (0.77)
Interference scores (Flanker task)	Training	24.63 (18.41)	24.55 (10.93)	26.06 (11.60)
	Control	39.56 (36.36)	32.89 (17.58)	24.58 (22.49)
PSWQ	Training	68.30 (6.59)	67.30 (7.26)	66.60 (7.29)
	Control	67.86 (5.09)	63.24 (9.78)	62.00 (10.25)
WDQ	Training	55.85 (18.67)	49.15 (20.11)	43.95 (20.28)
	Control	61.48 (13.83)	49.52 (17.28)	46.38 (18.40)
STAI-TA	Training	54.40 (7.85)	52.30 (9.57)	51.12 (10.13)
	Control	56.00 (7.60)	53.57 (9.72)	49.90 (9.11)
Number of negative intrusions pre-worry (breathing focus task)	Training	2.00 (1.62)	1.15 (1.69)	1.10 (1.71)
	Control	2.05 (1.88)	1.05 (1.20)	1.14 (1.56)
Number of negative intrusions post-worry (breathing focus task)	Training	2.80 (2.26)	2.00 (1.78)	2.15 (1.93)
	Control	3.33 (2.24)	2.67 (2.31)	2.43 (2.20)
Reactivity of negative intrusions (breathing focus task)	Training	0.80 (2.46)	0.85 (1.69)	0.95 (2.32)
	Control	1.29 (2.12)	1.67 (2.33)	1.29 (2.05)

Note: CDT, Change Detection Task; PSWQ, Penn State Worry Questionnaire; SD, Standard deviation; STAI-SA, State Anxiety Inventory; STAI-SA, Trait Anxiety Inventory; VAS, visual analogue scale; WDQ, Worry Domains Questionnaire.

The association between improvement on the *n*-back task and changes in WMC as measured by the CDT was also assessed. Training-related improvement on the *n*-back task, as measured by improvement in mean *n*-back level between the first and last two training days (mean improvement), positively correlated with greater improvements in CDT performance, pre to post training, $r(17) = .41$, $p = .040$, 95% CI [-0.054, 0.73] (see Figure 4). Likewise, measuring training improvement using training slope produced similar effects: significant CDT improvement pre- to post-training, $r(17) = .43$, $p = .032$, 95% CI [-0.03, 0.74].

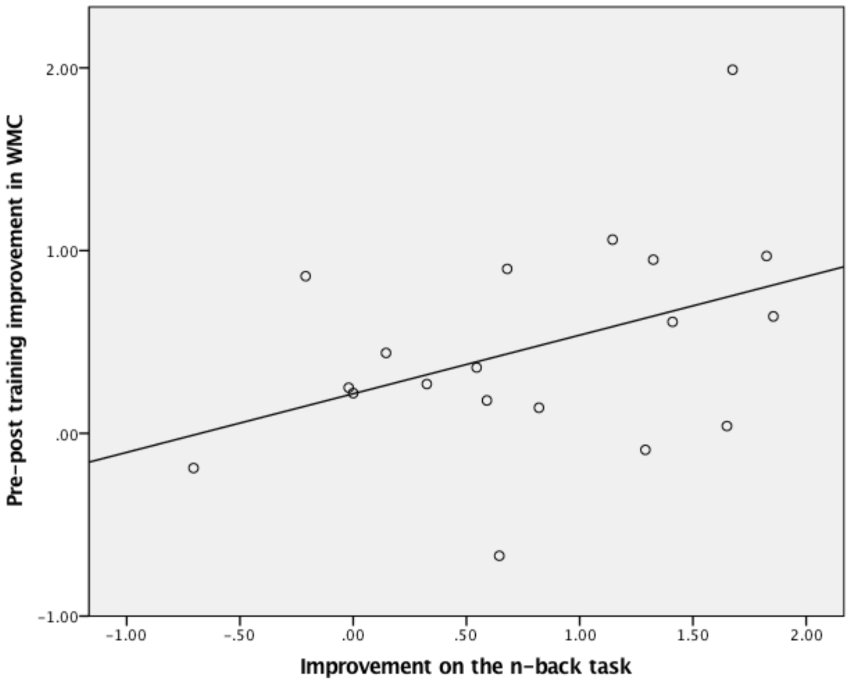

Figure 4. Graph to show the significant association between mean improvement on the *n*-back task and improvement on the four-item condition of the CDT (pre-post training).

Flanker task. A mixed model ANOVA with a between-subjects factor of group (control, training) and within-subjects factor of time (pre-training, post-training, follow-up) revealed that there was no significant effect of time on Flanker interference scores, indicating that participants' distractor inhibition did not improve over time as a result of training, $F(2, 64) = 1.58$, $p = .21$, $\eta_p^2 = .047$. There was also no significant effect of group, $F(1, 32) = 1.46$, $p = .24$, $\eta_p^2 = .044$, or time × group interaction, $F(2, 32) = 2.35$, $p = .10$, $\eta_p^2 = .068$, suggesting that the two groups had equivalent interference scores.

Breathing focus task. Data for this task was analysed using a mixed model ANOVA, with a between-subject factor of group and within-subjects factors of time and breathing period (pre-worry vs post-worry). There was a significant main effect of time, $F(2, 78) = 9.48$, $p < .001$, $\eta_p^2 = .195$, 95% CI [0.051, 0.33], with Bonferroni corrected post hoc testing indicating significant reductions in the number of negative intrusive thoughts between pre-training (M = 2.55, SD = 1.99) and post-training (M = 1.72, SD = 1.72) as well as at follow-up (M = 1.71, SD = 1.83). There was also a significant main effect of breathing period, $F(1, 39) = 19.90$, $p < .001$, $\eta_p^2 = .34$, 95% CI [0.11, 0.52] with significantly greater negative intrusive thoughts post-worry (M = 2.56, SD = 2.12) compared to pre-worry (M = 1.42, SD = 1.72). There were no significant main effects or interactions, all $Fs < 1$, *NS*.

A significant correlation was observed at baseline between the change in anxiety visual analogue scale ratings across the two breathing periods and the change in negative intrusions across the two breathing periods, $r(36) = .50$, $p < .001$.

Training-related improvement on the *n*-back task, as measured by mean improvement, did not significantly correlate with change in negative intrusions between the two breathing periods (reactivity) pre-training to follow-up, $r(18) = -.27$, $p = .13$. Similar findings were observed when training slope was used as a measure of training improvement, $r(18) = -.28$, $p = .11$.

Self-report Measures

Separate mixed model ANOVAs with between-subjects factors of group and within subjects factors of time found a significant main effect of time for each outcome measure: PSWQ, $F(1.73, 67.1) = 6.54$, $p = .004$, $\eta_p^2 = .14$, 95% CI [0.018, 0.29]; WDQ, $F(1.52, 59.33) = 21.69$, $p < .001$, $\eta_p^2 = .35$, 95% CI [0.16, 0.50]; STAI-TA, $F(2, 78) = 8.96$, $p < .001$, $\eta_p^2 = .19$, 95% CI [0.028, 0.29]. Bonferroni corrected post hoc tests showed that the PSWQ ($p = .011$), WDQ ($p < .001$) and STAI-TA ($p = .002$) scores all significantly improved between pre-training and follow-up. WDQ ($p = .001$) scores also significantly improved between pre-training and post-training. No significant group × time interactions or main effects of group were observed for any measures ($p > .05$ for all measures), suggesting that groups did not significantly differ with regards to the degree to which they improved as a result of training.

There was a significant association between changes in worry pre- and post-training, as measured by the PSWQ, and improvement on the *n*-back task as measured by mean improvement, $r(18) = -.43$, $p = .029$, 95% CI [-0.73, 0.015] (see figure 5), and as measured by training slope, $r(18) = -.45$, $p = .023$, 95% CI [-0.74, -0.009] with those participants who improved more on training reporting greater reductions in worry. No other associations between either measure of improvement on the *n*-back task and changes in self-report symptomatology were significant (p's > .05). However, the reduction in worry as measured by the PSWQ also significantly correlated with reductions in worry as measured by the WDQ, $r(18) = .57$, $p = .004$, 95% CI [0.17, 0.81] and reductions in trait anxiety as measured by the STAI-TA, $r(18) = .44$, $p = .026$, 95% CI [-0.003, 0.74].

Role of Perfectionism

There was a significant positive correlation between baseline perfectionism, as measured by the FMPS, and improvements in *n*-back performance, as measured by mean improvements in performance from the first two days to the last two days of training, $r(18) = .41$, $p = .038$, 95% CI [-0.04, 0.72] and as measured by training slope, $r(18) = .48$, $p = .017$, 95% CI [0.048, 0.76]. This suggests that levels of perfectionism may have influenced participant's engagement in training.

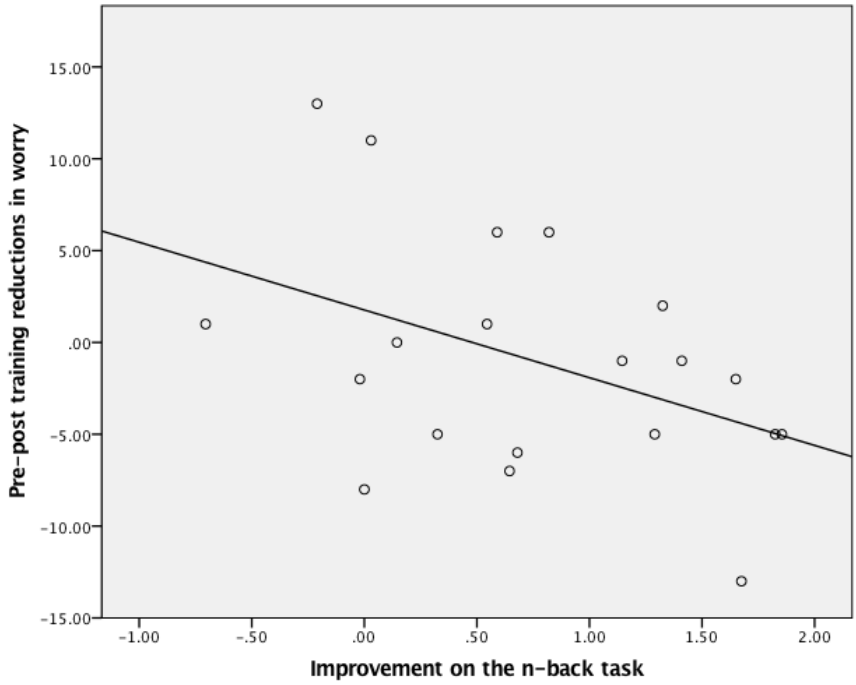

Figure 5. Graph to show the significant association between improvement on the *n*-back task and reductions in self-reported worry (PSWQ; pre-post training).

Discussion

The current study investigated whether adaptive visual *n*-back WMT can improve working memory and its associated attentional control processes in worry-prone individuals. It also aimed to assess whether any such improvements would generalise to reductions in self-reported worry and anxiety, as well as to performance on a behavioural measure of worry (a breathing focus task). A main finding of the current investigation was that adaptive *n*-back training led to similar improvements in working memory and self-reported symptoms of worry and anxiety to that of the 1-back control group. Consistent with previous research (Sari et al. 2016; Course-Choi et al., 2017) we also found that adaptive training-related reductions in worry depended upon training-related improvements in performance on the *n*-back task.

Many cognitive training studies have been criticized for failing to find that training effects transfer to other, untrained, tasks of working memory (Melby-Lervåg et al, 2016; Shipstead et al., 2012), so it was important that the CDT was included here as a measure of

WMC, in addition to solely measuring improvement in *n*-back performance. As with previous studies in non-vulnerable populations we also found no overall transfer to untrained measures of WM (cf., Melby-Lervåg et al, 2016; Shipstead et al, 2012). However, in line with previous training studies that have used the *n*-back training paradigm (Au et al., 2014), participants in the active training condition did demonstrate significant improvement in working memory performance over a period of 15 days. Of particular interest was the observation that training-related gains on the *n*-back task were found to be significantly associated with gains in CDT performance[3]. This provides some indication of a meaningful relationship between improvement on the *n*-back task and improved WMC, which certainly warrants further exploration.

In terms of self-reported symptomatology, once again there was no significant between training-group differences post-training or at follow-up with both groups reporting improvements in worry and anxiety, as measured by the WDQ, PSWQ and STAI-TA between pre-training and follow-up. Furthermore, worry (WDQ) improved significantly between pre-training and post-training, with scores on the PSWQ also showing a trend towards significance. While both groups showed significant improvements in worry over time, as with the CDT, training-related improvements on the *n*-back task were associated with a reduction in worry symptomatology, as measured by the PSWQ. This finding resembles the effects found in a sample of high trait anxious individuals (Sari et al. 2016), and high worriers (Course-Choi et al. 2017), where training-related improvements on a dual *n*-back task were associated with reductions in self-report trait anxiety and trait vulnerability to worry, respectively. A significant association between improvements in training performance and self-reported emotional vulnerability suggests that training related improvements in vulnerable populations may not form a uniform distribution. Rather, the slope of improvement may be different across individuals, which again, attests to more tailored interventions depending on the trajectory of working memory performance. Given that the promise of the impact of adaptive cognitive training is growing considerably in research targeting emotional vulnerability (see Motter, 2016, and Koster et al., 2017 for systematic reviews), this finding deserves further attention.

During the breathing focus task, both groups demonstrated equivalent significant reductions over time in the number of negative intrusions experienced. However, the lack of a three-way interaction between group, time and breathing period indicated that there was no evidence that training improved participants' reactivity to a five-minute worry period. A significant correlation between the change in anxiety visual analogue scale ratings and change in negative intrusions across the two breathing periods at baseline provides further evidence for the validity of this task as a measure of worry. Given that self-report measures are particularly susceptible to bias, it was important that an objective measure of worry was included in the present study. The finding that both objective and subjective measures used in this study demonstrated a comparable pattern of improvement within, but not between groups, provides further support for the argument that WMT does not lead to far-transfer effects (Melby-Lervåg et al., 2016), above-and-beyond the effects of control training. However, an important consideration for the current study is the low number of pre-training negative intrusive thoughts reported by both groups potentially creating a floor-effect, which subsequently may have reduced the sensitivity of this task to identify group differences over time. This was one of the first studies to use the breathing focus task (see also Fox et al., 2015) in a repeated measures design and further research must determine whether the task is sensitive enough to detect group differences.

Results on the Flanker task were not in the expected direction, with neither group demonstrating improved ability to ignore distracting interference. This finding may be due to the absence of any far-transfer effects following WMT (Melby-Lervåg et al., 2016). It may also be due, however, to the relatively undemanding nature of the version of the Flanker task used in this study. For instance, Attentional Control Theory (Berggren & Derakhshan, 2013; Eysenck et al., 2007) predicts that greater cognitive load can exacerbate the negative effects of worry and anxiety on attentional control. This prediction was supported by the finding of Sari et al. (in press) that improvements in resisting distracting information post-WMT in the flanker task were greater when state anxiety was manipulated using a burst of white noise, a finding not observed in the control condition. Future research into WMT in high-worriers would benefit from examining improvements in attentional control under more stressful conditions that necessitate the active exercise of attentional control processes necessitating inhibitory control. In addition, due to extreme outliers, data for seven participants was removed from the analysis of this task in the current study, potentially leaving this analysis under-powered.

We did find a significant correlation between improvement on the *n*-back task (as measured by both training slope and improvement in mean *n*-back level), and improvements in WMC and reductions in self-reported worry symptomatology. This could potentially be interpreted as indicating that those participants who showed greater improvements on the *n*-back task, experienced greater gains in WMC, and subsequently developed better top-down attentional control during a worry episode, resulting in fewer worry symptoms. There has been a recent shift within the WMT literature to focus on individual differences, rather than viewing WMT as a “one size fits all” intervention. Indeed, within-group analysis of training performance is indicative of heterogeneity in training-related improvements on the *n*-back task. This begs the question of what this variation represents. One argument (Course-Choi et al., 2017; Sari et al., in press) is that it reflects motivation and engagement with training. von Bastian and Oberauer (2014) have argued for the importance of including measures such as the Intrinsic Motivation Inventory (Ryan & Deci, 2000) to ensure that motivation is really associated with training-related gain. While we did not include this measure in the current study, the fact that higher perfectionism at baseline was associated with greater training-related gains might be interpreted as indicating that individuals who were high in perfectionism were more likely to engage in training with the aim of achieving a higher level of performance. While speculative, this is something that is worthy of further research.

It has been argued that personality traits, as well as motivation, could interact with WMT-specific factors and subsequently affect training-related gains (for reviews, see von Bastian & Oberauer, 2014; Jaeggi, Buschkuehl, Shah, & Jonides, 2013). Although this offers one potential explanation for the association between training-related gains on the *n*-back and reductions in worry, it is important to consider that within-group variance in such gains may not be reducible to one key personality trait or construct. As such, if individual differences do impact on WMT-related improvement, then much more research is required to determine the mechanisms involved in this. Since it is likely that participants' learning rates may also influence the effects of WMT (Moreau, 2014), it is possible that a useful line of future research would be to investigate the role of individual differences in engagement and commitment on the effects of training.

Clinical Implications, Limitations and Future Research

Hirsch and Mathews' (2012) cognitive model of pathological worry posits that a worry-episode is a product of reduced "top-down" attentional control, along with the presence of "bottom-up" biases towards negative information. The results of the current study indicated that WMT did not increase the WMC or decrease the worry symptoms of worry-prone individuals, above-and-beyond active control training. Therefore, if WMT is to be a realistic treatment (or preventative) option for worry-prone individuals, future research should continue to use active control training groups so as to ensure that improvements following training do not simply reflect placebo effects.

Despite the inability to reject the null hypothesis that WMT would lead to greater improvements in WMC when compared to control training, of potential interest was the association between training-related improvements on the *n*-back and improvements in WMC and worry symptoms. Such a finding may be reflective of individual differences, which may play a central role in the utility of WMT, with motivation and engagement in training being potentially important elements. If WMT is to be an effective intervention, future research should also investigate for whom it works best, and why.

It is important to highlight the fact that the active control group often demonstrated similar gains to the WMT group. One possibility is that training-related improvements were a result of expectancy, test-retest or placebo effects. However, the active control group also involved an element of (non-adaptive) training of working memory and therefore it was unsurprising to also observe some gains in this group. It may also be prudent to consider that in being a “worry-prone” sample, improvements in the control group may reflect non-specific aspects of training, such as adherence to a training schedule (Klingberg, 2010).

Unfortunately, this study did not find any effects of training on a behavioural measure of attentional control (the Flanker task). As discussed, this is perhaps a consequence of “ceiling” effects and the Flanker task not being carried out under conditions of high anxiety. Future research should examine effects of WMT for worry-prone individuals on a version of the Flanker task which includes a stress-related manipulation.

It may also be relevant that those participants who did not complete training had significantly lower baseline scores of perfectionism, anxiety and worry. The extent to which this impacted on the overall results of the study is not clear. However, given the hypothesized role of personality and motivation in training engagement (Jaeggi et al., 2013), it could be argued that these participants would be predicted to demonstrate lower improvements in WMC than those who completed training. Furthermore, since non-completers had lower baseline worry scores, they may have been less motivated to reduce their worry, which may have subsequently had an impact on training engagement.

The current study aimed to train working memory using the single visual *n*-back task, rather than the more commonly used dual (verbal/visual) *n*-back task. This was because of a previous research finding that these two tasks have equivalent effects (Jaeggi et al., 2010). However, given that worry is often verbal in nature (Hirsch & Mathews, 2012), future studies investigating cognitive training effects may be maximised by using the single verbal *n*-back task or dual *n*-back tasks. Furthermore, given that pathological worry appears to result from an interaction between "top-down" and "bottom-up" processes (Hirsch & Mathews, 2012), future research may benefit from investigation of the combination of WMT with interventions which aim to reduce "bottom-up" biases, such as interpretation bias modification (Hayes, Hirsch, Krebs, & Mathews, 2010).

Conclusion

Although adaptive WMT led to improvements in the WMC of worry-prone individuals, such improvements were not above-and-beyond the benefits of control training. However, of interest was the observation that training-related improvements on the *n*-back task were associated with reductions in self-reported worry symptomatology. It would therefore be helpful for future research to investigate the factors underlying this association.

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Footnotes

1. More recently, research has indicated that rather than using a dual *n*-back training task focusing on both visual and verbal working memory, a single visual *n*-back WMT task are equally effective at training working memory (Jaeggi, Studer-Luethi, Buschkuehl, Su, Jonides, & Perrig, 2010), meaning that simpler *n*-back training paradigms may lead to equivalent outcomes.
2. In line with Owens et al. (2013) and Sari et al. (2015), we report results from the four-item condition. This is due to "ceiling effects" often observed in the two-item condition and "floor effects" observed in the distractor condition.
3. Similar effects were not observed for the distractor condition; however, this may be explained by "floor effects", due to the complexity of this condition (Owens et al., 2013), and which inspection of the data indicated may also have happened in the current study.