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Trait Worry is Associated With Difficulties in Working Memory Updating

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Abstract

The current study investigated the effects of trait worry, a subcomponent of trait anxiety, on the process of updating information in working memory (WM). A leading theory on anxiety and executive functions, attentional control theory (Eysenck, Santos, Derakshan, & Calvo, 2007), states that anxiety is not related to WM updating in emotionally neutral situations. Previous research, however, has focused almost exclusively on WM span tasks that primarily emphasized storage, rather than the updating of WM representations. Moreover, few studies have directly examined the effects of trait worry. In this study, 116 subjects performed a WM updating task that required the memorization of short lists of words and the within-trial removal of some of these items from WM. Results indicated that levels of trait worry were not related to word span performance, but were related to performance on trials that required subjects to effectively update WM. Moreover, these effects were observed only for trait worry, not for levels of anxious arousal or comorbid levels of dysphoria. These results support the hypothesis that trait worry is related to WM updating performance and thereby extend attentional control theory in new directions.

Keywords

trait worry; anxiety; working memory updating; executive function

The relationship between trait anxiety and working memory (WM) has been tested in various empirical studies, but the research in this field has focused almost exclusively on WM span tasks that emphasized temporary storage of information in WM. WM updating, defined here as the “constant monitoring and rapid addition/deletion of WM contents” (Miyake & Friedman, 2012, p. 9), has been rarely examined in this literature, even though WM updating is one of the most frequently studied executive functions (Miyake et al., 2000; Miyake & Friedman, 2012).

On the basis of Miyake et al.’s (2000) framework on executive functions, a leading theory, called attentional control theory (ACT; Eysenck & Derakshan, 2010; Eysenck, Santos, Derakshan, & Calvo, 2007), has proposed that anxiety is not systematically associated with

WM updating ability unless situations are threatening, such as when using anxiety-inducing words as stimuli. However, because the prior studies have focused on WM span tasks that do not heavily implicate the within-trial updating WM representations, it is not yet clear whether “updating does not directly involve attentional control, and so anxiety does not impair the updating function under nonstressful conditions” (Eysenck et al., 2007, p. 347).

In this study, we focused on trait (as opposed to state) anxiety, especially its subcomponent, trait worry, and examined whether individual differences in levels of trait worry among young healthy adults are systematically related to their performance on a reaction-time (RT) based WM updating task. Modeled after Oberauer (2001, 2005), this task places a heavy demand on the efficient and effective within-trial removal of no-longer-relevant information from WM. Using this RT-based task, we tested three hypotheses regarding how trait worry may be related to WM updating performance.

Attentional Control Theory and Limitations of Previous Research

ACT and WM Updating

ACT consists of a set of six hypotheses regarding the relationship between subclinical levels of anxiety and cognitive ability (Eysenck et al., 2007). It makes a clear conceptual distinction between state and trait anxiety and proposes that “state anxiety (the currently experienced level of anxiety) is determined interactively by trait or test anxiety and by situational stress” (Eysenck et al., 2007, p. 336). The review of the evidence offered in this seminal work regarding each of the six hypotheses considers both state and trait anxiety, although some sections rely more heavily on the data based on trait anxiety than on state anxiety (as is the case with their section on WM updating).

Three of the six hypotheses (Hypotheses 4-6) put forth by Eysenck et al. (2007) are most directly relevant to the current study, and they focus on how levels of anxiety (at both the state and trait levels) are related to three correlated yet separable facets of executive functions postulated in Miyake et al.’s (2000) framework: the updating of WM representations (hereafter, WM updating or simply updating), the flexible shifting of mental or task sets (shifting), and the inhibition of dominant or prepotent responses (inhibition). ACT (Eysenck et al., 2007) proposes that anxiety is related to impaired processing efficiency for two of these three executive functions, inhibition (Hypothesis 4) and shifting (Hypothesis 5), but claims that updating is spared in anxiety unless it is tested in threatening situations (Hypothesis 6).

Eysenck et al. (2007, pp. 347-348) reviewed some evidence supporting this latter claim about the lack of a systematic relationship between anxiety and updating (e.g., Calvo & Eysenck, 1996; Calvo, Ramos, & Estevez, 1992; Darke, 1988), relying mostly on studies that examined the effects of trait anxiety (or combined trait and state anxiety) on WM storage measures. Although some more recent findings have suggested that trait anxiety (or its subcomponent, trait worry) might be related to worse performance on WM span tasks in adults (Crowe et al., 2007) and in children (Owens et al., 2012; Visu-Petra, Cheie, Bengel, & Alloway, 2011), the effects of trait anxiety/worry were not observed across all span tasks

administered in these studies. Only some of the WM span measures demonstrated the effects of trait anxiety/worry.

Another growing body of work has suggested that there may also be some functional neurological differences between high and low anxious individuals during tasks requiring WM updating (e.g., Basten et al., 2012; Fales et al., 2008). For example, in one study, even though no differences were observed at the behavioral level, higher levels of trait anxiety were related to greater activation in two brain regions thought to aid in goal-directed control and attention (i.e., the dorsolateral prefrontal cortex and left inferior frontal sulcus) during a delayed response task involving WM updating (Basten et al., 2012). Moreover, although a recent update to ACT based on neuroscientific evidence on anxiety and executive functions (Berggren & Derakshan, 2013) still posited that anxiety is related to updating only under stressful conditions, this review qualified this claim by explicitly acknowledging that systematic neuroscientific research that examines the anxiety-updating relationship has been lacking, especially that using complex updating tasks (such as N-back task). Given this current state of evidence, further investigation into the extent to which trait anxiety is related to performance on WM updating tasks is not only timely but also seems necessary.

Three Key Limitations of the Existing Evidence

The current study on the relationship between trait worry and WM updating was motivated by what we consider three important limitations of the existing evidence in the literature. First, as already noted, although ACT's theoretical claim is based on the notion of WM updating, prior studies have focused almost exclusively on prevalent storage-oriented WM span tasks, whether simple (e.g., word span) or complex (e.g., reading span). In particular, those WM span tasks do not require subjects to actively monitor WM representations and, when necessary, select and remove no-longer-relevant information from WM within a given trial. Thus, WM tasks that more directly tax this updating-related aspect of WM processes may be better suited for examining ACT's claim regarding the anxiety-updating relationship.

Second, because most existing research has relied on WM span tasks, the main dependent measures used in these studies are typically recall accuracy, not RTs. Given that another major tenet of ACT, processing efficiency hypothesis (Eysenck et al., 2007), explicitly states that anxiety primarily affects processing efficiency (often assessed with RTs) more so than performance effectiveness (often assessed with accuracy), the prior emphasis on accuracy-based measures may have led to an underestimation of the relationship between anxiety and updating. In fact, the two other facets of executive functions that ACT claims are systematically related to anxiety even in nonthreatening situations, inhibition and shifting, have often (if not always) been assessed with RT-based measures. Thus, it is important to assess WM updating with RT-based measures, too, to gain a better understanding of the relationship between anxiety and updating.

Third, prior research has not systematically examined the effects of different subcomponents of anxiety. Most existing studies on anxiety and WM, both those cited by Eysenck et al. (2007) and those published since, have used only broad measures of trait or test anxiety (Calvo & Eysenck, 1996; Calvo et al., 1992; Visu-Petra et al., 2011), without simultaneously using scales that measure worry more directly, such as the Penn State Worry Questionnaire

(Meyer, Miller, Metzger, & Borkovec, 1990). This is potentially an important issue, given that some researchers have argued that, because trait anxiety is multifaceted, the relationship between anxiety and another construct may not be revealed clearly unless anxiety is decomposed into some of its components (Heller, Nitschke, Etienne, & Miller, 1997; Nitschke, Heller, Palmieri, & Miller, 1999). From this perspective, focusing exclusively on a broad measure of trait anxiety may mask a potentially substantial effect of worry if trait worry, as opposed to, say, another subcomponent of trait anxiety, anxious arousal, is indeed the primary contributing factor systematically related to the efficiency of WM updating processes.

In fact, there is good reason to suspect that trait worry may be related to updating ability. Trait worry is a tendency to have repetitive negative thoughts about an anticipated future event that can be difficult to remove from mind (Ehring & Watkins, 2008; Watkins, 2008). This difficulty in removing negative thoughts from mind may represent an inherent underlying relationship between worry and WM updating, even in neutral, nonthreatening situations. For example, if worriers have general difficulty removing information from WM, then this tendency might explain why worriers struggle with repetitive negative thoughts.

These considerations suggest that the relationship between anxiety and updating may be observed most clearly when a specific measure of trait worry (as opposed to broad measures of trait anxiety) is used. This might be particularly true when the WM task is RT-based (as opposed to accuracy-based) and places a heavy demand on the online monitoring and updating of WM representations, including the removal of no-longer-relevant information.

Three Hypotheses Tested in the Study

In light of these considerations, we tested the following three hypotheses regarding the relationship between trait worry and updating. First, trait worry is related to worse performance efficiency on a WM updating task that requires the within-trial removal of no-longer-information from WM. Second, trait worry is not systematically related to performance on trials that are more storage-oriented (e.g., word span). Finally, these effects are specific to trait worry and are not driven by other components of anxiety (e.g., anxious arousal).

The Current Study

We tested these three hypotheses by adapting a WM updating task developed by Oberauer (2001, 2005). In this paradigm, illustrated in Figure 1, subjects memorized two short lists of words (red vs. blue). In the key trials involving WM deletion (90% of all trials), the color of the box presented in the center (e.g., red) indicated that one list would remain relevant whereas the other should be removed from WM. After a short cue-to-stimulus interval (CSI), a probe word appeared in this box, and a subject responded by identifying whether the displayed word was in the relevant list (relevant probes) or from another source: the irrelevant list (irrelevant probes) or a list of words not previously studied (new probes). Thus, to perform well on this task, subjects had to interpret the color cue, select the items that belonged to the irrelevant list, and quickly remove them from WM before responding to the subsequent probe word. In the remaining 10% of the trials of the WM task, subjects

simply recalled the originally presented lists of words. These word-span trials not only encouraged subjects to encode and memorize all of the presented words on each trial (as opposed to guessing which color might be relevant and selectively memorizing some of the words), but also provided a storage-oriented measure of word span within the context of the same WM task.

In the key WM deletion trials, four experimental manipulations used by Oberauer (2001, 2005) were included to shed light on the nature of the worry–updating relationship. First, short (250 ms) and long (1,000 ms) CSIs were included to test whether worry was related to the speed of removal. The effect of worry may be small for short CSIs where no one is realistically expected to be able to fully remove irrelevant information, but the effect of worry may be exaggerated at longer CSIs. Second, we also separately varied list length of both the relevant list (1 or 3 words) and the irrelevant list (1 or 3 words) to examine whether the effect of worry was stronger when more information needed to be retained or removed from WM.

The most important manipulation in this study, however, was the probe type (relevant, irrelevant, or new probes). For all three types of probes, subjects were expected to remove the words from the irrelevant list from WM and respond to the probe, but the processes involved in making a correct response were different. In trials with relevant probes, subjects must confirm that the probe is one of the words that they retained in their WM. Thus, in this condition, effective removal of irrelevant words should be indirectly helpful in that having only relevant words in WM would likely make this verification process easier. In contrast, in trials with irrelevant probes, the probe word comes from the list that subjects were supposed to remove from their WM. Thus, if this probe word is not effectively removed from WM, rejecting that probe will be difficult. Therefore, this irrelevant probe condition is most directly related to the testing of the effect of trait worry on WM updating. Finally, the trials with new probes served as the control condition. Because the probe word is entirely new in this condition, subjects should be able to reject this probe simply on the basis of familiarity, regardless of whether they have managed to remove words from the irrelevant list from WM. Thus, the probe verification process in this condition did not rely on the effectiveness of removing irrelevant information from WM.

The first hypothesis we tested in this study, namely that worriers have difficulty with WM deletion, predicts that trait worry will be related to slower RTs on the WM-deletion trials where information must be removed from WM within each trial. Specifically, we predicted that worry would be related to longer RTs on irrelevant probes, but not for new probes for which effective removal of irrelevant information is not crucial.

We did not make any strong a priori predictions regarding the relevant probes condition, because the effect of WM removal on the probe verification process is indirect, as explained above. If worry is related to the efficiency of removing irrelevant information per se, we may expect to find a significantly larger effect of worry for irrelevant probes than for relevant probes. It also seems possible, however, that trait worry is also related to other WM updating processes necessary to perform this task, such as rapidly and accurately selecting the right information to remove and deciding whether the probe word matches any of the items still

maintained in WM. If so, the effects of trait worry could be observed for these relevant probes as well. Thus, the extent to which trait worry is systematically related to the RT data for the relevant probes could provide insights as to whether the effect of trait worry on WM updating is specific to the removal of irrelevant information or may also encompass some other related processes.

The second hypothesis predicts that, like most previous research on anxiety and WM span recall, levels of worry will not be related to performance on the 10% of trials assessing word span. Finally, if worry is the primary component of the association between anxiety and updating, as proposed in the third hypothesis, then the effects of trait worry on RTs for WM-deletion trials should be observed even after controlling for levels of anxious arousal—another component of trait anxiety characterized by physiological symptoms rather than repetitive negative thoughts.

In addition to testing these specific predictions, the current study also addressed an additional prevalent methodological limitation present in most prior studies on this topic. Although it is well known that levels of dysphoria (more generally, depression) are highly comorbid with levels of anxiety (Mineka, Watson, & Clark, 1998), these effects of comorbidity are not usually statistically controlled for in the existing research on anxiety and executive functions (e.g., Calvo et al., 1992; Crowe et al., 2007; Darke, 1988). This is a potentially important consideration, given that levels of dysphoria or depression have been known to be broadly associated with performance on executive function tasks (Altamirano, Miyake, & Whitmer, 2010; Robinaugh, Crane, Enock, & McNally, 2015; Snyder, 2013; Snyder, Miyake, & Hankin, 2015). To ensure that the effects observed in this study are specific to trait worry, and not due to influences of comorbid dysphoria, we administered measures of trait dysphoria in addition to the questionnaires assessing worry and anxious arousal and statistically controlled for the effects of dysphoria in our main analyses.

Method

Subjects

One-hundred sixteen undergraduate students (64 women and 52 men) participated for partial course credit¹.

Materials and Procedure

WM updating task.—All stimuli for the WM task were 1- or 2-syllable common nouns of neutral emotional valence, each used once over the course of the study. Numerical words (e.g., *five*), proper nouns (e.g., *Spain*), and nouns that are most frequently used as verbs (e.g., *jump*, *fall*) were excluded, and no single trial contained multiple words starting with the same letter. Because this is primarily an individual differences study, the list of stimuli used for each trial and the order of the trials were fixed after initial randomization so that all

¹Four of the 116 subjects reported that they were currently taking medication for anxiety and/or depression. To ensure that the results were not due to these subjects who may have clinical anxiety or depression, we reanalyzed the data with these subjects excluded. Doing so did not change the patterns of results. Further analyses were also performed excluding subjects who had BAI or BDI scores above cutoff values for “moderate” anxiety (total BAI > 16, $n = 16$) or depression (BDI > 20, $n = 13$). Again, these analyses did not change the pattern of results.

subjects memorized and responded to the same words (in the same order), thus minimizing measurement error due to subject $\times$ order interactions.

The experimental procedure for the WM task (consisting of a total of 240 trials) is schematically illustrated in Figure 1. Subjects first saw three red and three blue boxes appear for 650 ms. Then, a total of 2, 4, or 6 words (1 or 3 words for each color) were simultaneously presented for 1,300 ms per word, followed by a blank screen (700 ms). When only one word was presented in a color, it always occupied the middle box.

On the target trials of the WM task (90% of the trials) testing WM updating (Figure 1A), subjects then saw a cue, either a red or blue box presented in the center of the screen, indicating which list of words (red or blue) was the relevant list for that trial. After the CSI of 250 or 1,000 ms, a probe word, printed in capital letters, appeared inside this box. Each subject's task was to judge whether the probe word was from the relevant list or not by pressing the right button on a button box for a "yes" response and the left button for a "no" response. Probe types included words from the relevant list (relevant probes, 40%), words from the newly removed irrelevant list (irrelevant probes, 40%), and words from a list of words that had not been previously memorized (new probes, 20%).

On the remaining 10% of the trials (Figure 1B), subjects saw the sentence, "List all words that were displayed," appear in between the red and blue boxes. On those trials, subjects pointed to each box (in any order) and told the experimenter what word was presented in that box. Those trials not only encouraged subjects to encode and try to memorize all words on each trial but also served as a storage-oriented span measure that did not require any deletion. Subjects received a correct response only if they remembered the word in the correct box. Aggregated accuracy for these trials was the proportion of the 96 total words recalled during the task.

Questionnaires.—Trait levels of worry were measured with the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990), which consisted of 16 items with a 5-point rating scale per question. Anxious arousal was measured with the 21-item Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988), and trait levels of dysphoria were measured with the 21-item Beck Depression Inventory (BDI; Beck & Steer, 1987), both based on a 4-point rating scale per question².

Because we did not include an independent measure of anxious arousal in this study, we derived it by conducting an exploratory factor analysis of BAI items, following the original factor-analytic study of BAI (Beck et al., 1988). We used maximum likelihood estimation with an oblique (promax) rotation to allow for interfactor correlations. As in the Beck et al. (1988) study, a two-factor solution emerged (with an interfactor correlation of $r = .45$), with the first factor representing anxious arousal. The results of the factor analysis are summarized in Appendix A. As is clear from this table, items that seem to represent arousal

²Four additional questionnaires were administered as part of a larger study on the relationship between general repetitive negative thought and WM updating, although none of these measures were analyzed in this study. These additional questionnaires were: the Ruminative Responses Scale, the Five Facet Mindfulness Questionnaire, the Inventory of Depression and Anxiety Symptoms, and the Habit Index of Negative Thinking.

loaded highly on the first factor (e.g., “hands trembling,” “sweating,” “heart pounding”), whereas items related to fear (e.g., “fear of the worse happening,” “scared”) loaded on the second factor, which we interpreted as the fear/panic factor. Because this two-factor solution closely resembled that of the Beck et al. (1988) study, we use the factor scores for the first factor as a proxy for anxious arousal in the main statistical analyses reported below³.

Procedure.—Each session took approximately 90 min. Participants first performed the WM updating task and then completed the questionnaires (BAI, PSWQ, then BDI), both on a Macintosh computer. The WM updating task was programmed and administered using PsyScope 1.2.5 (Cohen, MacWhinney, Flatt, & Provost, 1993), and responses were recorded using a ms-accurate button box.

Preliminary Data Analysis

Accuracy and RT data from the WM updating task were analyzed with extreme RTs greater than 5 s removed (0.2% of the total trials), and only RTs from correct trials were included in the RT analyses. RTs longer than 2.5 SDs above a subject’s mean RT in that condition were trimmed to the mean plus 2.5 SDs to minimize any undue influences from outliers⁴.

Results

Questionnaire Data

Descriptive statistics and correlations for the questionnaire measures are summarized in Table 1. Although the overall level of trait worry was relatively low in this subclinical sample, the PSWQ scores correlated substantially with the BAI and BDI scores. Although hardly surprising, these correlations confirm the need to statistically control for comorbid mood variables to unambiguously attribute the observed results to trait worry.

Experimental Effects for the WM Updating Task

The main goal of this study was to test three hypotheses regarding the relationship between trait worry and WM updating. Before testing these hypotheses directly, however, we subjected the probe RT and accuracy data to ANOVAs that included four within-subjects experimental variables: CSI (250 ms vs. 1,000 ms), probe type (relevant, vs. irrelevant vs. new), relevant list length (1 vs. 3 words), and irrelevant list length (1 vs. 3 words).

Mean RTs and accuracies for all the conditions of the WM task are reported in the Table 2. Because the results of these basic experimental effects ANOVAs were not the focus of this research and were generally comparable to earlier results (Oberauer, 2001, 2005), we will not provide a description of these experimental effects in this article. Instead, we report a table summarizing the statistical results of these within-subjects variables in Appendix B.

³All analyses were also conducted using BAI total scores, but the use of this broad measure of trait anxiety did not change the overall pattern of results.

⁴We also performed arcsine and logarithmic transformations to improve the distributional characteristics of the accuracy and RT measures, respectively. However, these analyses revealed the same pattern of results as the nontransformed accuracy data and the 2.5-SD trimmed data.

Effects of Trait Worry on WM Updating (WM Deletion Trials)

Data analytic strategy.—To test the primary hypothesis that trait worry is associated with worse processing efficiency on certain trials of the deletion task (e.g., trials with irrelevant probes), but not others (e.g., those with new probes), we conducted multiple regression analyses, following the procedure outlined by Judd, McClelland, and Ryan (2008). In these analyses, all of the within-subjects effects reported in Appendix B (i.e., all main and interaction effects of the experimental variables) were still included in the model, but, in addition, worry, anxious arousal, and dysphoria were included as continuous variables predicting RT and accuracy, respectively, following the method recommended by Yzerbyt, Muller, and Judd (2004). For simplicity, however, no higher-order interactions among the clinical variables (e.g., worry $\times$ dysphoria) were included in the model. We treated the key individual differences variables (e.g., levels of trait worry) as continuous variables, rather than create discrete groups based on some arbitrary criterion (e.g., median-split), as has often been done in this field, because the creation of dichotomous groups using a continuous measure is associated with various statistical problems, such as reduced statistical power and spurious results (Irwin & McClelland, 2003; MacCallum, Zhang, Preacher, & Rucker, 2002).

For the testing of our primary hypothesis, we examined whether the worry variable interacted significantly with the experimental manipulations included in the WM updating task, especially with the probe type manipulation. A significant interaction between worry and probe type, for example, indicates that subjects with high and low levels of trait worry differed significantly in their responses to different types of probes, thus demonstrating an association between worry and WM updating performance. For graphical purposes, Figure 2 depicts levels of trait worry at plus and minus 1 SD (e.g., high worry vs. low worry), following the commonly used Aiken and West (1991) procedure. However, all the analyses were done treating the individual differences in clinical variables as continuous.

In this section, we report whether (and if so how) trait worry interacted with the experimental factors in the ANOVA (e.g., probe type, CSI) and whether levels of trait worry had any effect on overall RTs and accuracy scores (i.e., the main effect of trait worry), both types of analyses controlling for any systematic effects attributable to anxious arousal and dysphoria. The effects of anxious arousal and dysphoria are reported later.

Probe RT.—As illustrated in Figure 2A, the key interaction of probe type $\times$ worry was significant, $F(2, 112) = 4.53, p = .012, \eta^2_p = .04$, indicating that trait worry was associated with processing efficiency on some probe types more so than others. Consistent with our first hypothesis, further analysis indicated that individuals who reported high levels of trait worry produced significantly longer RTs for irrelevant probes, $F(1, 112) = 5.30, p = .023, \eta^2_p = .05$, but not for new probes, $F(1, 112) = 1.14, p = .287, \eta^2_p = .01$. Moreover, higher levels of trait worry were also associated with significantly longer RTs for relevant probes, $F(1, 112) = 4.84, p = .030, \eta^2_p = .04$, a finding that we will discuss in more detail in the Discussion section. Given that trait worry was associated with worse processing efficiency for two of the probe types, it is not surprising that the main effect of worry was also significant, $F(1, 112) = 4.13, p = .044, \eta^2_p = .04$.

In contrast to the results for the probe type manipulation, levels of trait worry did not interact with the other three experimental manipulations, namely, CSI, $F(1, 112) = .30, p = .584, \eta^2_p = .00$, relevant list length, $F(1, 112) = .01, p = .914, \eta^2_p = .00$, or irrelevant list length, $F(1, 112) = 2.24, p = .138, \eta^2_p = .02$. These results suggest that the effects of trait worry did not depend on how quickly information needed to be removed (CSI), or the amount of information to be retained (relevant list length) or removed from WM (irrelevant list length). None of the higher-order interactions involving worry were also significant, all $F_s < 2.19, p_s > .114, \eta^2_p < .02$, with one exception that was not predicted a priori and seems difficult to interpret⁵.

Probe Accuracy.—The probe $\times$ worry interaction was not significant for analyses involving the accuracy data, $F(2, 112) = 2.06, p = .130, \eta^2_p = .02$. As shown in Figure 2B, worry was not related to accuracy for irrelevant probes, $F(1, 112) = 3.23, p = .075, \eta^2_p = .03$, relevant probes, $F(1, 112) = .81, p = .369, \eta^2_p = .01$, or new probes, $F(1, 112) = .14, p = .712, \eta^2_p = .00$. The main effect of worry was also not significant, $F(1, 112) = 2.54, p = .114, \eta^2_p = .02$.

As was the case with the probe RT data, worry did not interact with CSI, $F(1, 112) = .16, p = .694, \eta^2_p = .00$, relevant list length, $F(1, 112) = .63, p = .430, \eta^2_p = .01$, or irrelevant list length, $F(1, 112) = 1.39, p = .242, \eta^2_p = .01$. None of the higher-order interactions involving worry were also significant, all $F_s < 1.98, p_s > .140, \eta^2_p < .02$.

Summary.—Consistent with our primary hypothesis, trait worry was associated with longer RTs for trials that specifically tapped the efficiency of WM deletion (i.e., irrelevant probes), but not for trials that did not depend on successful removal of no-longer-relevant information (i.e., new probes). Furthermore, consistent with ACTs processing efficiency hypothesis, worriers were able to achieve the same level of accuracy on the WM updating task.

Effects of Trait Worry on Word Span Trials

We also tested whether trait worry would be associated with performance on the word-span trials by conducting a regression analysis analogous to those reported above, treating levels of trait worry, anxious arousal, and dysphoria as continuous variables allowed to simultaneously predict span accuracy. Although, not surprisingly, the main effect of set size (2, 4, or 6 words) was highly significant, $F(2, 112) = 377.80, p < .001, \eta^2 = .77$, but worry was not predictive of overall accuracy, $F(1, 112) = .06, p = .810, \eta^2 = .00$, nor did it interact with set size, $F(1, 112) = .28, p = .757, \eta^2 = .00$, as predicted by our second hypothesis. Additionally, as reported in Table 1, no zero-order correlations were significant between trait worry and recall accuracy not only at each set size but also at the level of aggregated accuracy across all trials. Thus, the word-span results are largely consistent with the

⁵There was a significant 3-way interaction between CSI, relevant list length, and worry, $F(1, 112) = 3.97, p = .049, \eta^2_p = .03$. To understand this interaction, we conducted further analyses by collapsing across the probe type and irrelevant list length manipulations. These analyses revealed that the effect of trait worry was strongest for short-CSI trials with short relevant list lengths ($r = .21, p = .027$), compared to short-CSI trials with long relevant lists ($r = .16, p = .090$), or long-CSI trials with short ($r = .16, p = .086$) or long relevant lists ($r = .13, p = .164$). Because this interaction was barely significant, was not predicted a priori, and is difficult to interpret, it might be a case of Type I error due to multiple statistical tests.

suggestion that trait worry is not related to recall accuracy on storage-oriented WM span tasks in nonthreatening situations.

Effects of Trait Arousal and Dysphoria

Finally, we tested the third hypothesis that the observed effects on WM updating were specific to trait worry, rather than another component of anxiety, anxious arousal, or a highly comorbid construct, dysphoria. In general, in the same full regression models reported above that controlled for the effects of other clinical variables, the relevant interactions between a clinical variable (anxious arousal or dysphoria) and the within-subjects experimental manipulations were not statistically significant for any of the dependent measures (i.e., the probe accuracy, probe RT, and word span data), all $F_s < 2.92$, $p_s > .089$, $\eta^2_p < .03$, for anxious arousal, and $F_s < 2.72$, $p_s > .101$, $\eta^2_p < .03$, for dysphoria⁶. The only exceptions were two interactions for the probe RT data, one between dysphoria and the CSI manipulation, $F(1, 112) = 4.43$, $p = .037$, $\eta^2 = .04$, and the other between dysphoria and the irrelevant list length manipulation, $F(1, 112) = 6.77$, $p = .011$, $\eta^2 = .06$. Visual inspections of these interactions suggested that slower RTs observed for short CSIs or longer irrelevant lists were more pronounced for subjects with higher levels of dysphoria. Important to note, however, dysphoria was not related to RTs on any probe types, $F_s(1, 112) < .18$, $p_s > .675$, $\eta^2 < .01$, even though worry showed clear probe type effects. These results suggest that the interaction between worry and the probe type manipulation reported earlier for the RT data was specific to trait worry.

Discussion

Main Results of the Study

The current study tested three hypotheses regarding whether trait worry is related to performance on a WM updating task. The study yielded three important findings. First, trait worry interacted with the probe type manipulation such that subjects with high levels of trait worry responded more slowly to the relevant and irrelevant probes, but not to the new probes. Second, we did not find a relationship between trait worry and performance on storage-oriented word-span trials. Third, these effects were observed even when controlling for levels of anxious arousal and dysphoria, which, in turn, were largely unrelated to performance on WM updating (although levels of dysphoria showed some independent effects on RTs). These findings provide support for the three hypotheses and suggest that trait worry may be systematically associated with WM updating ability even in nonthreatening situations.

Before discussing the implications of these results, we briefly note here some limitations and qualifications of the current study. First, the reported effects are for subclinical levels of worry, anxious arousal, and dysphoria. The effects of these mood variables may be different if examined at the clinical level. Second, we did not have an independent measure of anxious arousal in this study and had to statistically derive from the BAI. However, the exploratory

⁶We also conducted additional analyses in which only one mood variable (worry, anxious arousal, or dysphoria) was included in the model, without controlling for the other trait tendencies. For all clinical variables, these analyses yielded results that were qualitatively similar to those reported in the main text.

factor analysis we conducted revealed a pattern almost identical to the one obtained by Beck et al. (1988), and the items that loaded on the first factor seemed to be clearly related to anxious arousal (Appendix A). Thus, our factor-score measure likely tapped anxious arousal reasonably well, though this aspect of the results must be cautiously interpreted.

Theoretical and Methodological Implications of the Study

The results of this study have some important theoretical implications, especially regarding ACT's claim that, unlike inhibition and shifting, updating ability is spared in neutral, nonthreatening situations (Eysenck et al., 2007). In line with ACT, we did not find much effect of overall trait anxiety as measured by BAI (see Footnote 3), or one of its subcomponent, anxious arousal, on WM updating performance. However, we found a systematic effect of another subcomponent of trait anxiety, trait worry, on WM updating, even in emotionally neutral situations. As noted earlier, the review of the evidence on the anxiety-updating relationship in the original Eysenck et al. (2007) article focused mostly on the data based on broad trait anxiety measures, not more specific measures of trait worry. Thus, to the extent that ACT's scope encompasses trait worry, our finding suggests a need for a potential reexamination of ACT's claim on WM updating. In particular, our results suggest a need for more precisely specifying which aspect (state or trait) or which component of anxiety (worry or anxious arousal) is systematically associated with updating ability and which aspect or component is not.

In the remainder of this section, we discuss the more specific implications of the current study. Specifically, we consider (a) the specific subprocesses of WM updating that might be linked to trait worry, (b) the extent to which the current results based on trait worry reflects the effects of state worry, and (c) the need for examining the comorbid effects in future studies of anxiety and worry.

Aspects of WM updating impaired in trait worry.—The current study used a WM updating task that puts a premium on the effective deletion of no-longer-relevant information. As we alluded to in the introduction, however, WM updating is a complex process that consists of multiple subprocesses. In light of our finding that trait worry was systematically related to the RTs for not only irrelevant probes but also relevant probes, what can we say about the specific subprocesses of WM updating affected by trait worry?

Although we still cannot conclusively rule out the possibility that worry is related only to the process of removing information from WM, the results of the current study suggest that the effect of worry on WM updating may go beyond the removal of WM elements per se. If trait worry were related only to irrelevant probe RTs (but not to relevant probe RTs) or if the effect of trait worry were much bigger for irrelevant probe RTs than for relevant probe RTs, then such results would allow us to pinpoint the source of the trait worry effect to the removal of irrelevant information from WM. However, the finding that levels of trait worry were related to impaired efficiency for the processing of relevant probes as well suggests that, in addition to (or possibly even instead of) deleting irrelevant information from WM, trait worry may also be related to (a) quickly and accurately selecting which piece of information to remove from WM before removal happens, and/or (b) deciding whether the

probe word matches any of the items still maintained in WM. In fact, if these two component processes operate inefficiently, such difficulties should influence the processing of both relevant and irrelevant probes, but not new probes. Although this interpretation is speculative, it provides a basis for future empirical testing.

Even though we cannot yet precisely pinpoint which subprocesses of WM updating are affected in trait worry, it is important to note that the other aspects of the probe RT data help us rule out some other interpretations of the results. For example, the lack of an interaction between trait worry and CSI suggests that the speed with which no-longer-irrelevant information needs to be removed from WM is unlikely to be the source of the worry effect, at least at those specific CSIs tested in this study (250 ms & 1,000 ms)⁷. In addition, given that the effects of worry also did not depend on how much information needed to be retained in WM (1 vs. 3 relevant words) or removed from WM (1 vs. 3 irrelevant words), the memory load itself is unlikely the sole factor for the reduced efficiency in WM updating among worriers. Last but not the least, the finding that worry was related to the probe RTs for relevant and irrelevant probes but not for new probes suggest that worriers were not generally slower in their processing speed.

Trait worry's impacts on WM updating.—So far, our discussion of the results has focused on the specific subprocesses of WM updating, but another important issue to consider is the mechanisms with which levels of trait worry might be systematically linked to individual differences in the efficiency of WM updating. We can think of two alternative explanations.

The first possibility is that the effects of trait worry on WM updating efficiency observed in the current study are due primarily to state effects of worry. ACT defines worry as “the component of state anxiety responsible for the effects of anxiety on performance effectiveness and efficiency” and assumes that worry is “most likely to occur in individuals high in trait anxiety” (Eysenck et al., 2007, p. 337). Thus, one possibility is that individuals with high levels of trait worry were actually having worrisome thoughts during the study, which in turn interfered substantially with the efficiency of WM updating performance. Although this “state worry” account seems possible for some subset of the subjects, it is not entirely clear how likely it is, given that another key assumption of ACT is that “worry is activated in stress situations (especially in test, evaluative, or competitive conditions)” (Eysenck et al., 2007, p. 337). There was nothing in the study procedure or stimuli that could have strongly elicited worries among the subjects (as we noted in the procedure section, all subjects also performed the WM updating task before completing any clinically relevant questionnaires).

An alternative (but not necessarily mutual exclusive) possibility, however, is that there are some systematic trait-level differences in the way high-worry and low-worry individuals

⁷Prior research (Oberauer, 2001) has indicated that, whereas a CSI of 250 ms may be too fast for anyone to completely remove information from WM, a CSI of 1000 ms may be long enough for almost all subjects to be able to effectively remove from WM items belonging to even these long lists. Thus, in retrospect, other CSIs, such as those for which some subjects might struggle to remove long lists but others might not (e.g., 600-750 ms), might have been better suited to reveal any effect of trait worry on the speed of removing irrelevant information from WM.

engage in cognitive processing. As discussed in the introduction, worry is characterized by repetitive negative thoughts about future events (Ehring & Watkins, 2008; Watkins, 2008), and a worrier's struggle with such repetitive thoughts may represent an underlying trait-level characteristic that operates above and beyond the detrimental effects of state worries. In fact, Watkins (2008; Ehring & Watkins, 2008) has made a compelling case for the view that the degree to which an individual regularly experiences negative repetitive thoughts, be they about future events (as in worry) or past events (as in rumination), is a stable traitlike characteristic. Consistent with this view, some recent studies on rumination have shown that ruminators' WM may be "sticky" (Altamirano, et al., 2010, p. 1378) in that, once established, some thoughts or goals might not easily slip out of their WM (Altamirano et al., 2010; Joormann, Levens, & Gotlib, 2011; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Whitmer & Banich, 2007). Although this "mental stickiness" idea has not been explored in the context of trait worry, it provides a principled explanation of why worriers have difficulty removing unwanted negative repetitive thoughts (i.e., worry) from their WM.

The results of the current study cannot discriminate between these two different interpretations, but these considerations point to a strong need to test these accounts in future studies, possibly by directly measuring both trait and state worry. Moreover, as has been done in some recent studies (e.g., Basten et al., 2012; Fales et al., 2008), examining the effects of trait anxiety or trait worry on WM using cognitive neuroscience paradigms (e.g., neuroimaging, ERPs) also seems highly fruitful (Berggren & Derakshan, 2013). Such studies may help illuminate how high and low trait worriers differ (structurally and/or functionally) in the way they process information in WM even in emotionally neutral, nonstressful situations

Methodological implications for future studies.—Finally, we would like to briefly emphasize here two important methodological implications of the current research. First, although prior research on the effects of anxiety on executive functions tended to use a broad measure of anxiety, it is important to assess not only multiple components of anxiety (worry, anxious arousal) but also other known comorbid variables (e.g., dysphoria). Otherwise, it would be impossible to attribute an observed effect specifically to, say, worry, given that these measures are substantially correlated with each other. Second, as noted briefly earlier, the use of continuous variables, rather than the creation of dichotomous groups based on arbitrary criteria (e.g., median split), should also alleviate some well known statistical concerns about the latter, still fairly common practice in the field (see Irwin & McClelland, 2003; MacCallum et al., 2002). In this regard, another common practice, the use of an extreme group design, also requires great caution (see Preacher, Rucker, MacCallum, & Nicewander, 2005).

Concluding Remarks

Using a RT-based WM updating task that placed heavy demands on the removal of no-longer-relevant WM representations, the current study demonstrated that trait worry is systematically related to the efficiency of WM updating performance, at least among this subclinical sample of young adults. In particular, our results suggest that the field needs further systematic investigation into the anxiety–WM relationship that puts more emphasis

on the multifaceted nature of both WM and anxiety. Prior research on the effect of anxiety on WM mostly used storage-oriented span tasks, but WM is not just about storage. It clearly involves other processes (e.g., monitoring and effective removal of no-longer-relevant information), but those other aspects of WM have rarely been examined, especially using RT-based measures. The same can be said about anxiety. Like WM, anxiety is not a unitary construct, either, and includes multiple subcomponents (e.g., worry, anxious arousal), but little systematic examination of the effects of different subcomponents of anxiety on WM has been conducted. The current study suggests that a more fine-grained analysis of the anxiety-WM relationship that takes such multifaceted nature of both WM and anxiety will be needed for further theoretical advances.

More generally, although the current study featured a task that puts a premium on the within-trial removal of irrelevant information, there is emerging evidence that trait worry is related to other WM processes as well. For example, recent studies have shown that trait worriers have difficulty with the effective or efficient gating of information in WM (i.e., “letting in” only the task-relevant information into WM), especially when that information is threatening (Owens, Derakshan, & Richards, 2015; Stout, Shackman, & Johnson, & Larson, 2015). The current study is part of this growing literature documenting the dynamic interplay between trait worry and WM. Going beyond the storage functions of WM and considering different stages of WM processes (e.g., encoding, monitoring, deletion, manipulation, retrieval) would likely be most fruitful in future research.

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Appendix A: Results of the Exploratory Factor Analysis of BAI

Item	Factor 1 (Anxious Arousal)	Item	Factor 2 (Fear/Panic)
Dizzy or lightheaded	.84	Fear of the worst happening	.73
Shaky	.63	Scared	.70
Faint	.63	Nervous	.69
Hands trembling	.62	Fear of losing control	.63
Feeling hot	.61	Terrified	.55
Unsteady	.60	Fear of dying	.37
Wobbliness in legs	.58	Heart pounding or racing	.34
Numbness or tingling	.47	Face flushed	.28
Sweating (not due to heat)	.46	Unable to relax	.27
Heart pounding or racing	.44	Difficulty breathing	.24
Unable to relax	.38	Indigestion or discomfort in abdomen	.17
Indigestion or discomfort in abdomen	.37	Feelings of choking	.14
Face flushed	.31	Unsteady	.10

Item	Factor 1 (Anxious Arousal)	Item	Factor 2 (Fear/Panic)
Difficulty breathing	.31	Wobbliness in legs	.04
Feelings of choking	.18	Sweating (not due to heat)	.03
Terrified	.07	Numbness or tingling	-.01
Fear of the worst happening	.05	Faint	-.02
Nervous	-.04	Shaky	-.08
Fear of losing control	-.10	Feeling hot	-.10
Fear of dying	-.10	Dizzy or lightheaded	-.17
Scared	-.11	Hands trembling	-.21

Note: Factor analysis was performed with maximum likelihood and Promax rotation. The two factors were correlated moderately, $r = .45$. The items are displayed in order of their highest loading on the first (left) or second (right) factor.

Appendix B: A Summary of the Complete ANOVA Results for the Experimental Effects of the WM Updating Task

Variable	RTs			Accuracy		
	<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2
Probe	172.70 (2, 115)	< 0.001	0.600	99.18 (2, 115)	< 0.001	0.463
CSI	575.10 (1, 115)	< 0.001	0.833	0.39 (1, 115)	0.531	0.003
Relevant Length	610.64 (1, 115)	< 0.001	0.842	127.28 (1, 115)	< 0.001	0.525
Irrelevant Length	90.16 (1, 115)	< 0.001	0.439	31.83 (1, 115)	< 0.001	0.217
Probe $\times$ CSI	77.80 (2, 115)	< 0.001	0.404	4.97 (2, 115)	0.008	0.041
Probe $\times$ Relevant Length	82.51 (2, 115)	< 0.001	0.418	30.87 (2, 115)	< 0.001	0.212
Probe $\times$ Irrelevant Length	15.45 (2, 115)	< 0.001	0.118	18.74 (2, 115)	< 0.001	0.140
CSI $\times$ Relevant Length	116.89 (1, 115)	< 0.001	0.504	15.13 (1, 115)	< 0.001	0.116
CSI $\times$ Irrelevant Length	32.13 (1, 115)	< 0.001	0.218	12.99 (1, 115)	< 0.001	0.101
Relevant Length $\times$ Irrelevant Length	0.39 (1, 115)	0.531	0.003	11.26 (1, 115)	0.001	0.089
Probe $\times$ CSI $\times$ Relevant Length	32.92 (2, 115)	< 0.001	0.223	15.31 (2, 115)	< 0.001	0.117
Probe $\times$ CSI $\times$ Irrelevant Length	9.14 (2, 115)	< 0.001	0.074	15.29 (2, 115)	< 0.001	0.117
Probe $\times$ Relevant Length $\times$ Irrelevant Length	19.61 (2, 115)	< 0.001	0.146	5.19 (2, 115)	0.006	0.043
CSI $\times$ Relevant Length $\times$ Irrelevant Length	2.85 (1, 115)	0.094	0.024	6.16 (1, 115)	0.015	0.051
Probe $\times$ CSI $\times$ Relevant Length $\times$ Irrelevant Length	1.47 (2, 115)	0.233	0.013	8.21 (2, 115)	< 0.001	0.067

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Figure 1:
An example of the trials on the WM task. 90% of trials required deletion (A) and 10% of trials measured word span (B).

Figure 2:

The effect of trait worry, controlling for arousal and dysphoria, on RT (A) and accuracy (B) across the three probe types. “High” and “Low” refers to the regression model predictions for plus or minus one standard deviation of PSWQ scores (* indicates significant effects, $p < .05$).

Table 1: Descriptive Statistics and Correlations Between Questionnaires and Performance on Trials Assessing Word Span

Measure	Mean	SD	Range	Skewness	Kurtosis	Reliability	Correlation w/ questionnaires		
							BAI Factor 1	PSWQ	BDI
Anxiety (BAI total score)	10.4	7.3	0 - 32	0.75	-0.18	0.86	.85*	.50*	.56*
Factor 1 (Arousal)	0.0	0.9	- 1.0 - 2.7	1.09	0.48	0.85	-	.30*	.39*
Factor 2 (Fear/Panic)	0.0	0.9	- 1.1 - 2.2	0.66	-0.81	0.77	.51*	.55*	.55*
Worry (PSWQ)	46.2	14.8	18 - 76	0.00	-0.82	0.71		-	.50*
Dysphoria (BDI)	10.6	9.8	0 - 43	1.42	2.24	0.92			-
Word Span (% correct)									
2 words	0.99	0.04	.75 - 1	-5.27	30.20	-	.03	.02	.12
4 words	0.87	0.10	.50 - 1	-1.09	1.25	-	.02	-.03	.06
6 words	0.66	0.17	.25 - 1	-0.12	-0.84	-	-.09	.01	.05
Aggregated total	0.81	0.11	.44 - 1	-0.56	0.27	-	-.05	-.01	.07

Note: Reliability was calculated using Cronbach's Alpha. (* indicates a significant correlation). Reliability for the BAI Factor 1 (arousal) was calculated for the 15 BAI items that loaded more highly on this factor than factor 2 (fear), and vice-versa (6 items)

Table 2:
Means for the Within-Subject Factors of the Working Memory Task Requiring Deletion

Probe	CSI	Relevant Length 1			Relevant Length 3				
		Irrelevant Length 1	Mean	SE	Irrelevant Length 1	Mean	SE		
Accuracy									
Relevant	250	97.7	0.4	94.8	0.8	94.0	0.9	90.3	1.0
	1250	98.3	0.4	96.4	0.7	96.3	0.6	90.0	1.0
Irrelevant	250	94.1	0.8	96.1	0.6	91.3	1.1	92.7	0.8
	1250	98.3	0.5	97.4	0.4	92.5	0.9	85.6	1.2
New	250	99.8	0.2	99.7	0.3	99.7	0.2	99.0	0.5
	1250	99.8	0.2	99.4	0.3	97.8	1.0	99.0	0.3
Reaction Time									
Relevant	250	1007	31	1134	33	1392	33	1516	43
	1250	765	23	881	30	1164	33	1243	41
Irrelevant	250	1332	48	1378	40	1454	41	1684	43
	1250	942	35	1013	38	1347	40	1506	53
New	250	865	28	1018	26	968	23	1035	23
	1250	815	29	813	21	1073	33	988	26

Note: RTs (in milliseconds) and accuracies (in percent correct) for all conditions.