Trait Worry is Associated With Deletion Difficulty But Not Storage Capacity:

Reexamining the Relationship Between Anxiety and Working Memory Updating

by

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Abstract

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Trait Worry is Associated With Deletion Difficulty But Not Storage Capacity: Reexamining the Relationship Between Anxiety and Working Memory Updating

Directed by Akira Miyake, Professor, Department of Psychology, University of Colorado at Boulder

This research investigates 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) states that trait anxiety is not related to WM updating, but some important aspects of WM updating have not been studied in this context - namely, the removal of irrelevant information from WM. In two studies, subjects completed simple (Study 1) and complex (Study 2) WM span tasks, questionnaires measuring trait levels of mood variables, and an updating task requiring the memorization of short lists of words and the within-trial removal of some of these items from WM. Although worry was not related to performance on any of the WM span tasks, the two studies provided the first evidence for a link between trait worry and WM updating on a deletion task. Furthermore, these results support the hypothesis that worry is related specifically to removing no longer relevant information from mind. Finally, these effects were observed solely for the trait worry component of anxiety, rather than levels of anxious arousal or comorbid levels of dysphoria. In light of these results, some aspects of attentional control theory need to be

revised, especially to account for the finding that one specific aspect of WM updating, namely deletion, is affected in worry.

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Chapter 1:

Introduction

General Introduction

In the past decade, a growing body of research has identified links between trait anxiety and executive functions (Eysenck & Derakshan, 2010; Eysenck, Santos, Derakshan, & Calvo, 2007). According to one influential theory known as attentional control theory (Eysenck et al., 2007), trait anxiety is associated with impaired performance efficiency for tasks involving inhibition (the overriding of dominant, automatic, or prepotent responses) and shifting (flexible switching back and forth between multiple tasks or mental sets), two of three major executive functions examined by Miyake et al.'s (2000) latent variable analysis. Attentional control theory, however, suggests that a third major executive function, WM updating (the monitoring, coding, and updating of working memory representations), is not impaired in nonthreatening situations (Eysenck et al., 2007). The current research evaluates, in two ways, this claim that WM updating is spared in trait anxiety.

First, the subcomponents of WM updating are decomposed in an attempt to identify a theorized link between trait anxiety and WM updating. WM updating is a complex process and contains many subcomponents. For example, it involves adding information to WM, monitoring and coding incoming information, deleting no longer relevant information, and replacing irrelevant information with relevant information (Miyake et al., 2000). Existing research on anxiety and WM updating, however, have focused solely on simple and complex WM span tasks (Calvo & Eysenck, 1996; Calvo, Eysenck, Ramos, & Jimenez, 1994; Calvo, Ramos, & Estevez, 1992), which do not rely heavily on some components of WM updating, particularly WM deletion: a complex subcomponent of WM updating that includes removing irrelevant information from mind and selecting relevant information to act on before and after successful removal. In fact, as will be noted later, there is good reason to suspect that WM deletion might be related to trait anxiety. Thus, in two studies, the relationship between trait anxiety and WM updating was examined using a task involving deletion. Furthermore, three theoretical hypotheses – persisting irrelevant thoughts, selection difficulty, and general slowdown – are evaluated to examine which best explains this relationship.

The other way attentional control theory is evaluated is by decomposing trait anxiety into its subcomponents, trait worry and anxious arousal (Nitschke, Heller, Imig, McDonald, & Miller, 2001), to see which subcomponent best explains the link between anxiety and executive functioning. Attentional control theory focuses on trait anxiety in general but proposes that worry is responsible for many of the effects of anxiety on task performance (Eysenck et al., 2007). However, the subcomponents of trait anxiety are not often tested specifically in the existing research (Calvo & Eysenck, 1996; Calvo et al., 1992; Darke, 1988), though there are some exceptions (Crowe, Matthews, & Walkenhorst, 2007). Furthermore, even though anxiety is highly comorbid with trait levels of dysphoria (Mineka, Watson, & Clark, 1998), levels of dysphoria are not often controlled for in research on trait anxiety (Calvo & Eysenck, 1996; Calvo, et al., 1994; Calvo et al., 1992). The aims of this research were both to provide evidence that trait worry is the component of anxiety most related to WM updating, and to show that these effects are specific to worry and not do to comorbid influences from dysphoria.

Anxiety and WM Updating

Attentional Control Theory and Subsequent Research

Attentional control theory (Eysenck et al., 2007; Eysenck & Derakshan, 2010) synthesizes previous research on trait anxiety and cognitive performance, especially between anxiety and executive functions. The focus of attentional control theory is on levels of anxiety in the subclinical population. In addition, its main hypotheses focus mainly on *trait* levels of anxiety, although some effects of state anxiety are discussed.

Attentional control theory consists of two main subtheories. One is an extension of processing efficiency theory proposed earlier (Eysenck & Calvo, 1992). This processing efficiency theory makes a distinction between performance effectiveness, the quality of performance usually measured with accuracy, and processing efficiency, the relationship between effectiveness and effort expended (Eysenck et al., 2007). Often efficiency is measured with reaction times (RTs), but other measures of efficiency include psychophysiolocal measures such as heart rate. Processing efficiency theory claims that anxious individuals can perform at the same level of effectiveness as nonanxious individuals, but at the expense of extra effort (less efficiency), regardless of how it is measured. Therefore, each of the hypotheses of attentional control theory that link anxiety to executive functioning incorporates the claim that performance efficiency is affected, rather than or at least more so than effectiveness. Finally, attentional control theory assumes that anxiety is related to performance effectiveness through one of its subcomponents, worry, because worrisome thoughts consume WM resources and cause auxiliary processing resources to be recruited to minimize the anxiety state (Eysenck et al., 2007).

The second subtheory of attentional control theory, which the current research focuses more directly on, concerns the relationship between anxiety and executive functioning. For example, three of the hypotheses of attentional control theory relate to the three unique but correlated executive functions examined by Miyake et al.'s (2000) latent variable analysis of inhibition, shifting, and WM updating. According to the original claims of attentional control theory, anxiety impairs inhibition and shifting, but

WM updating is spared in trait anxiety unless task conditions are stressful (Eysenck et al., 2007), such as when threatening instructions are implemented (Calvo et al., 1992; Darke, 1988). A number of studies published before their 2007 paper are consistent with the claim that WM updating is not affected in anxiety in nonstressful situations (Calvo & Eysenck, 1996; Calvo et al., 1992, 1994; Darke, 1988), but other recent research has provided some evidence that trait anxiety may be related to performance on some, but not other, WM span tasks (Crowe et al., 2007; Visu-Petra, Cheie, Benge, & Alloway, 2011).

Limitations of Previous Research

Although the idea that updating is not impaired has some support, there are a number of limitations. First, one major reason to suspect that trait anxiety may be related to WM updating is that the existing research has not tested important components of WM updating in the context of trait anxiety. The existing research has focused solely on simple or complex span tasks, in which the addition and active maintenance of target items in WM must take place (Calvo & Eysenck, 1996; Calvo et al., 1994; Crowe et al., 2007; Visu-Petra et at., 2011). Simple span tasks, such as the digit and word spans, usually involve just memorization and recall, whereas complex span tasks such as the reading span and operation span include a memorization task (e.g. remembering words), an unrelated processing task (e.g. reading and evaluating the validity of sentences), and finally a recall component. Important to note, neither simple nor complex span tasks heavily rely on a potentially important and complex component of WM updating, the within-trial deletion of information from WM. WM deletion is complex within itself. Depending on the task, correct information to remove must first be selected out of all the information currently stored in WM. Then, irrelevant information must be efficiently removed from WM while relevant information is preserved. After successful removal, recently removed information should not be reactivated. Finally, if previously relevant information is encountered again, more selection must take place to not allow this potentially distracting information back into WM. Some of these processes may be related to performance on complex span tasks, but others, especially the process of removing irrelevant information itself, are quite different from those used in complex span tasks, which usually involve only a distractor and a memorization task.

A second limitation is that subcomponents of anxiety are not frequently focused on in the existing literature, and this focus may be necessary to find effects (Heller & Nitschke, 1998; Heller, Nitschke, Etienne, & Miller, 1997). As mentioned, attentional control theory proposes that anxiety is related to performance efficiency through worry (Eysenck et al., 2007). However, many existing studies only use broad measures of trait anxiety (Calvo & Eysenck, 1996; Calvo et al., 1992; Visu-Petra et al., 2011), rather than focus on scales or subscales that measure worry more directly such as the Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990) or the apprehension subscale of Beck's Anxiety Inventory (Beck, Epstien, Brown, & Steer, 1988). If worry is the driving force behind the relationship between trait levels of anxiety and executive functioning, then it may be necessary to measure trait worry and control for the effects of anxious arousal, the other subcomponent of anxiety, to find effects (Heller & Nitschke, 1998; Heller et al., 1997).

In fact, there is good reason to suspect that the trait worry subcomponent of anxiety may be related to some or all of these components of WM deletion. Trait worry is defined as 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 underlying relationship between worry and WM deletion, even in nonstressful situations. Specifically, worriers may have irrelevant thoughts that are difficult to remove from mind because, in general, they cannot select the right thoughts to keep in WM, cannot remove thoughts they know are irrelevant, cannot select the right information to focus on after deletion (resulting in deleted thoughts entering back into or conflicting with relevant information in WM), or any combination of these factors.

A final limitation is that levels of depression and dysphoria are highly comorbid with levels of trait anxiety (Mineka, et al., 1998) and are also related to performance on executive function tasks (Altamirano, Miyake & Whitmer, 2010; Gotlib & Joormann, 2010). However, these effects are not usually controlled for in the existing research on trait anxiety and WM updating (Calvo et al.; 1992, 1994; Crowe et al., 2007; Darke, 1988). If these effects are not controlled for, it is possible that any observed relationship between anxiety and WM updating may be due to indirect influences from dysphoria. Therefore, it is important to measure levels of dysphoria in any study on trait anxiety and executive functioning, to ensure that any effect is due to the influence of anxiety and not comorbid dysphoria.

The Current Study

These limitations were addressed in two studies with three main goals. The first and primary goal was to investigate whether trait anxiety was related to performance on two WM updating tasks requiring deletion, and, if so, to evaluate which of three hypotheses best characterized this relationship. Second, simple (Study 1) and complex (Study 2) measures of WM span were implemented to investigate whether tasks without strong deletion components were also related to anxiety levels. Finally, the third goal was to examine whether trait worry is related to performance on the WM updating tasks, rather than the anxious arousal subcomponent of trait anxiety or comorbid levels of trait dysphoria.

In this research, I implemented a WM updating task based on one used by Oberauer (2001, 2005) to study WM deletion in nonclinical populations. In this paradigm, subjects always memorized two short lists of words. Later, a cue indicated that one list remained relevant whereas the other should have been removed from mind. After a short delay, a probe word appeared in this box, and a subject responded by identifying whether the displayed word was in the relevant list or from another source (e.g., the irrelevant list or a list of words not previously studied). To perform well on this task, subjects had to interpret the cue and quickly remove the irrelevant list from mind. When they saw the subsequent probe word, they also had to quickly select the correct source of the list. Subjects experience slowdown when they do not quickly remove the irrelevant list or cannot quickly select the source of the probe word. Thus, both the efficient removal of irrelevant information (removing the irrelevant list) and efficient selection (correctly identifying the source of the list) are key aspects of performance on this task.

Chapter 2:

Study 1

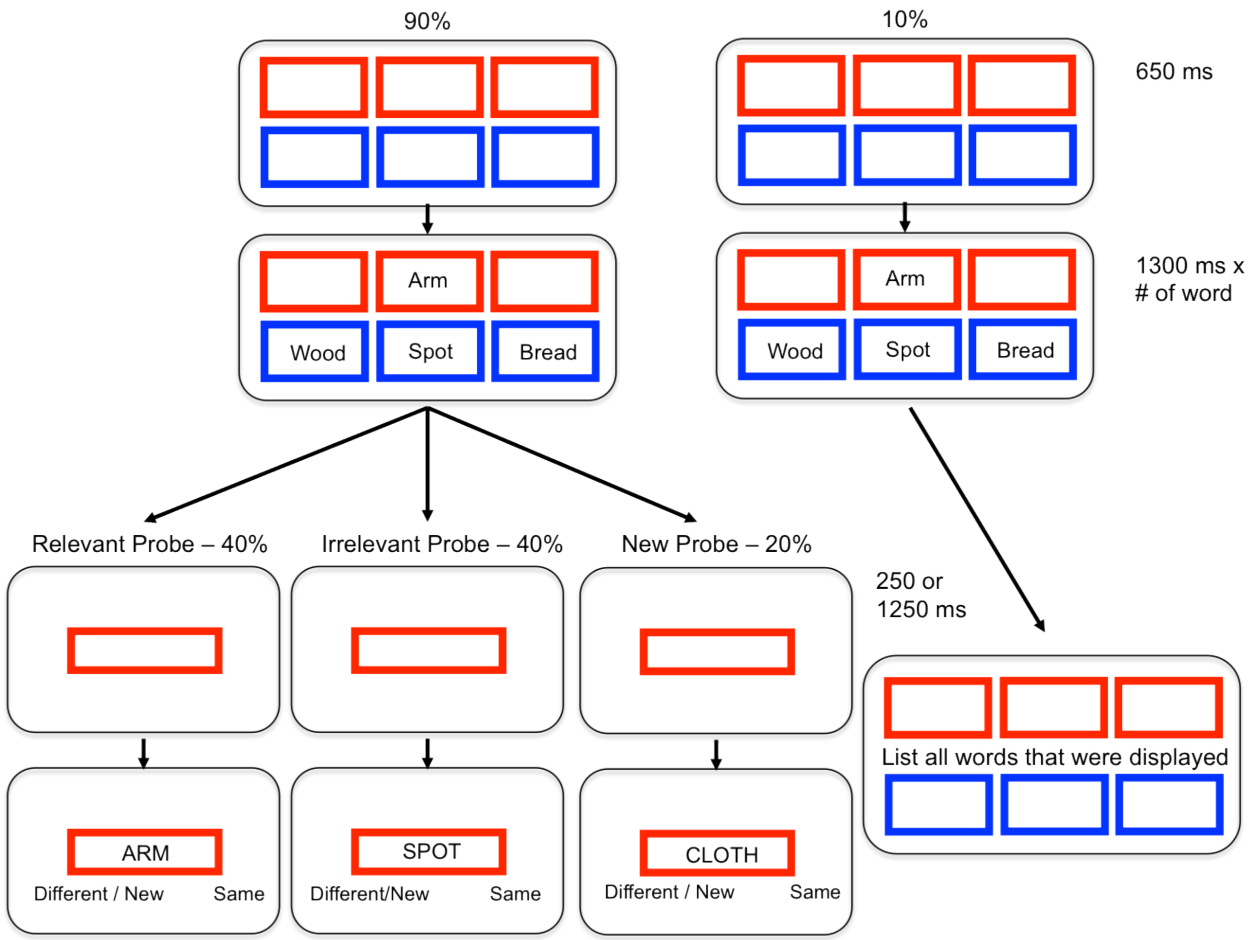
Study 1 Introduction

The WM deletion task used in Study 1, displayed in Figure 1, was similar to that used in Oberauer (2001), but modified to test whether anxiety was related to performance efficiency on trials that both did and did not have strong deletion requirements. Ninety percent of the trials of the WM task were nearly identical to Oberauer (2001). Subjects memorized two short lists of either one or three words each. Afterward, a colored box was presented indicating the relevant list, and subjects were instructed to remove the other from mind. Finally, after a cue-stimulus-interval (CSI) of either 250 or 1,250 ms, a probe word was displayed in the box. A subject responded by pressing one button on a button box if the word was from the correct list (relevant probes), and another button if the word was from the irrelevant list (irrelevant probes) or a list of words that was not previously learned (new probes).

On 10% of the trials of this task, displayed on the far column of Figure 1, subjects simply memorized the two lists and, after a short delay, were instructed to recall them. These 10% of trials were designed to encourage subjects to memorize all words during each trial. Additionally, this manipulation provided a simple measure of word span.

The first goal of this research was to examine a link between trait worry and WM updating hypothesized in the Introduction, and an important aspect of this goal is to understand why worry is related to WM deletion. In Study 1, three different hypotheses about how trait worry may be related to deletion are tested. Each proposes different mechanisms behind this relationship and makes different predictions about how worry will be related to performance on the WM deletion task. As suggested by processing

Figure 1: Conditions of the WM Task Used In Study 1



The conditions of the deletion component (90%) and span component (10%) WM deletion task used in Study 1 efficiency theory, each hypothesis assumes that trait worry will be related to processing efficiency (RTs in the context of this task), rather than performance effectiveness (accuracy).

The first hypothesis, the persisting irrelevant thoughts hypothesis, proposes that because trait worriers often know that their thoughts are irrelevant to accomplishing a future goal, but still have difficulty removing them from mind, worry is specifically related to efficiently removing irrelevant information from WM. This hypothesis is consistent with the idea that worries represent uncontrollable and unconstructive repetitive thoughts (Watkins, 2008) that are difficult to remove from mind. If this hypothesis is correct, worriers will struggle the most when they process irrelevant information. Because this hypothesis states that worry is related primarily to the processing of irrelevant information, it predicts that worry will be related most strongly to RTs on trials where subjects must respond to irrelevant information (i.e., irrelevant probes) after it should have been removed from mind. Relevant information (relevant probes) may also be affected because leftover irrelevant information in WM may interfere with the processing of this type of information, but because this effect is indirect, relevant information should be affected less. This hypothesis does not predict that new probes will be affected in this task.

The second hypothesis, the selection difficulty hypothesis, asserts that worry is not related to the removal of irrelevant information per se, but rather to efficiency in quick controlled selection of relevant information compared with irrelevant (or previously relevant) information. In contrast to the previous hypothesis, which suggests that worriers know which information is irrelevant but have trouble removing it, this hypothesis suggests that worriers may not be able to quickly select the correct information to be processed or acted on. This failure results in difficulty in distinguishing relevant from irrelevant information during WM updating, especially immediately after deletion when newly irrelevant information is still salient. This hypothesis is consistent with findings that trait worry was related to selection costs on a verb generation task requiring executive function resources (Snyder et al., 2010). In this task, this hypothesis predicts that worriers will perform more slowly on trials where relevant (relevant probes) or irrelevant (irrelevant probes) information must be identified, because it will be hard for worriers to select the correct source of the words. However, it does not predict that new information (new probes) will be affected because it is not difficult to distinguish previously learned words with novel ones.

The third hypothesis, the general slowdown hypothesis, proposes that trait worry is related to processing of all types of information on WM tasks requiring deletion. If the claim of attentional control theory that worry generally consumes WM resources is correct, efficiency should be impaired across all aspects of the deletion task because all conditions require utilization of WM resources. Therefore, this hypothesis predicts that worriers will respond more slowly for all types of probes on the deletion task. In addition, the general slowdown hypothesis predicts that the effects of worry will increase proportionally with task difficulty, because the hardest trials require the most WM resources. Therefore, this hypothesis also predicts interactions between worry and all of the main experimental manipulations (list length, CSI, and probe type).

The second goal was addressed by having subjects recall memorized words on 10% of the trials of the WM task. As mentioned, performance on these recall trials is a measure of word span. If span is affected in worry or anxiety, anxious individuals will perform worse on this component of the WM task.

Lastly, the third goal of this research was addressed by including measures of trait worry, anxious arousal, and dysphoria. As will be discussed later, the effects of each subcomponent of anxiety are analyzed controlling for the other subcomponent and levels of dysphoria.

Method

Subjects

Ninety-six undergraduate students (50 women and 46 men) participated for partial course credit.

Materials and Procedure

Each session took place over the course of 90 min. Participants first performed the WM task, followed by the questionnaires, on a Macintosh computer. The Beck Depression Inventory was performed last because it is the only questionnaire that has mood altering effects. The WM 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.

Questionnaires. Trait levels of worry were measured with the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990), which had 16 items with 5 response levels per question[1]. Anxious arousal was measured with the 12-item anxious arousal subscale of the Beck Anxiety Inventory (BAI; Beck et al., 1988), which had 4 response levels per question. Trait levels of dysphoria were measured with the 21-item Beck Depression Inventory (BDI; Beck & Steer, 1987), which also had 4 response levels per question. A short demographic questionnaire was also administered to acquire information about age and gender.

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[1] Worry was also measured with the apprehension subscale of the Beck Anxiety Inventory. The results were clearer for the PSWQ, so I am focusing on this measure here. Differences between the two measures are discussed in footnote 2 and in the General Discussion.

WM deletion task. An example of the WM task is illustrated in Figure 1. 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. Numbers, proper nouns (e.g., names of people or countries), and nouns that are most frequently used as verbs (e.g., 'jump', 'fall') were excluded. For each trial, words were randomly chosen from a list of approximately 1,300 nouns with the qualification that no trial contained multiple words starting with the same letter. After the initial randomization, stimuli were fixed so that all subjects memorized and responded to the same words.

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 deletion, 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 1,250 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. Relevant and irrelevant probe words made up 40% of the probes each, whereas new probes were presented 20% of the time.

On the remaining 10% of the trials, 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 in that box. 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.

Data Analysis

Accuracy and RT data from the WM deletion task were analyzed with extreme RTs greater than 5 s removed (.2% of the total trials), and RTs were analyzed for correct trials only. Then, RTs longer than 2.5 SDs above a subject's mean RT in that condition were trimmed to the mean plus 2.5 SDs. In addition, arcsine (accuracy) and logarithmic (RT) transformations were performed, but these analyses revealed the same pattern of results, so the nontransformed data are reported here.

Results

Questionnaire Data

The 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, PSWQ scores correlated significantly with the anxious arousal subscale of the BAI and with BDI score. Though hardly surprising, these correlations confirm the need to statistically control for comorbid mood variables to unambiguously attribute the observed results to trait worry.

WM Deletion Task: Experimental Effects

The probe accuracy and RT data were subjected to ANOVAs that included four within-subjects experimental variables: CSI (250 or 1,250 ms), probe type (relevant, irrelevant, or new), relevant list length (1 or 3 words), and irrelevant list length (1 or 3 words). Mean accuracies and RTs for each condition of the WM task are reported in Table 2, and ANOVA results of these conditions are reported in Appendix A. For both the accuracy and RT ANOVAs, many of the higher-level interactions between the within-subjects conditions were significant. However, because these interactions are not

Table 1: Descriptive Statistics and Correlations of Individual Differences Questionnaires and Aggregated Free Recall Trials in Study 1

							Correlation w/ questionnaires		
Measure	Mean	SD	Range	Skewness	Kurtosis	Reliability	Worry	Arousal	Dysphoria
Worry (PSWQ)	47.09	14.75	18 - 76	0	-0.85	0.71	-	0.36*	0.52*
Arousal (BAI-Arousal)	5.54	4.69	0 - 18	1.04	0.11	0.84		-	0.39*
Dysphoria (BDI)	9.71	9.10	0 - 40	1.45	1.99	0.92			-
Aggregate Free Recall Score	0.80	0.11	.52 - .99	-0.33	-0.49	0.79	-0.06	-0.1	0.02

Note: Reliability was calculated using Cronbach's Alpha. (* indicates a significant correlation, $p < .05$)

Table 2: Means for the Within-Subject Factors of the Working Memory Task in Study 1

		Relevant Length 1				Relevant Length 3			
		Irrelevant Length 1		Irrelevant Length 3		Irrelevant Length 1		Irrelevant Length 3	
Probe	CSI	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Accuracy									
Relevant	250	97.8	0.4	94.8	0.9	94.1	0.9	90.0	1.1
	1250	98.3	0.4	96.3	0.8	96.0	0.7	89.0	1.1
Irrelevant	250	94.5	0.8	96.1	0.7	91.3	1.2	92.9	0.9
	1250	98.4	0.5	97.5	0.5	92.7	1.0	85.6	1.3
New	250	99.7	0.3	99.7	0.3	99.6	0.2	99.0	0.5
	1250	99.7	0.3	99.3	0.3	97.9	1.0	98.8	0.4
Reaction Time									
Relevant	250	1000	30	1128	37	1373	35	1468	39
	1250	764	25	879	33	1165	35	1195	38
Irrelevant	250	1320	41	1389	44	1451	41	1662	46
	1250	952	38	1014	40	1345	38	1495	53
New	250	854	24	1020	28	975	25	1048	25
	1250	816	27	814	22	1062	36	979	27

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

the focus of this research and because these experimental effects were generally comparable to the results of Oberauer (2001, 2005), only the main effects of the within-subjects variables are discussed here.

Probe accuracy. As shown in Table 2, the probe accuracy was consistently high across three probe types. Similar to previous research by Oberauer (2001, 2005), the CSI manipulation was not related to accuracy, $F(1,95) < 1$, $\eta^2 = .00$, but subjects responded more accurately to trials with fewer relevant words, $F(1,95) = 114.81$, $p < .001$, $\eta^2 = .55$, and irrelevant words, $F(1,95) = 31.26$, $p < .001$, $\eta^2 = .25$. The probe main effect was also significant, $F(2,95) = 82.82$, $p < .001$, $\eta^2 = .64$, such that new probes were responded to most accurately ($M = 99\%$, $SE = 0.2\%$), followed by relevant ($M = 94.8\%$, $SE = 0.4\%$) and irrelevant probes ($M = 93.8\%$, $SE = 0.5\%$).

Probe RT. Also consistent with Oberauer (2001, 2005), the main effects of CSI, relevant list length, and irrelevant list length were significant. Subjects responded faster to trials with longer CSIs than shorter CSIs, $F(1,95) = 449.54$, $p < .001$, $\eta^2 = .83$, shorter relevant lists than longer relevant lists, $F(1,95) = 514.14$, $p < .001$, $\eta^2 = .84$, and shorter irrelevant lists than longer irrelevant lists, $F(1,95) = 77.48$, $p < .001$, $\eta^2 = .45$. Also, as expected, the main effect of probe type was significant, $F(2,95) = 145.06$, $p < .001$, $\eta^2 = .75$, such that irrelevant probes were associated with the slowest RTs ($M = 1346$ ms, $SE = 42$), followed by relevant ($M = 1145$ ms, $SE = 32$) and new probes ($M = 952$ ms, $SE = 24$).

WM Deletion Task: Effects of Trait Anxiety

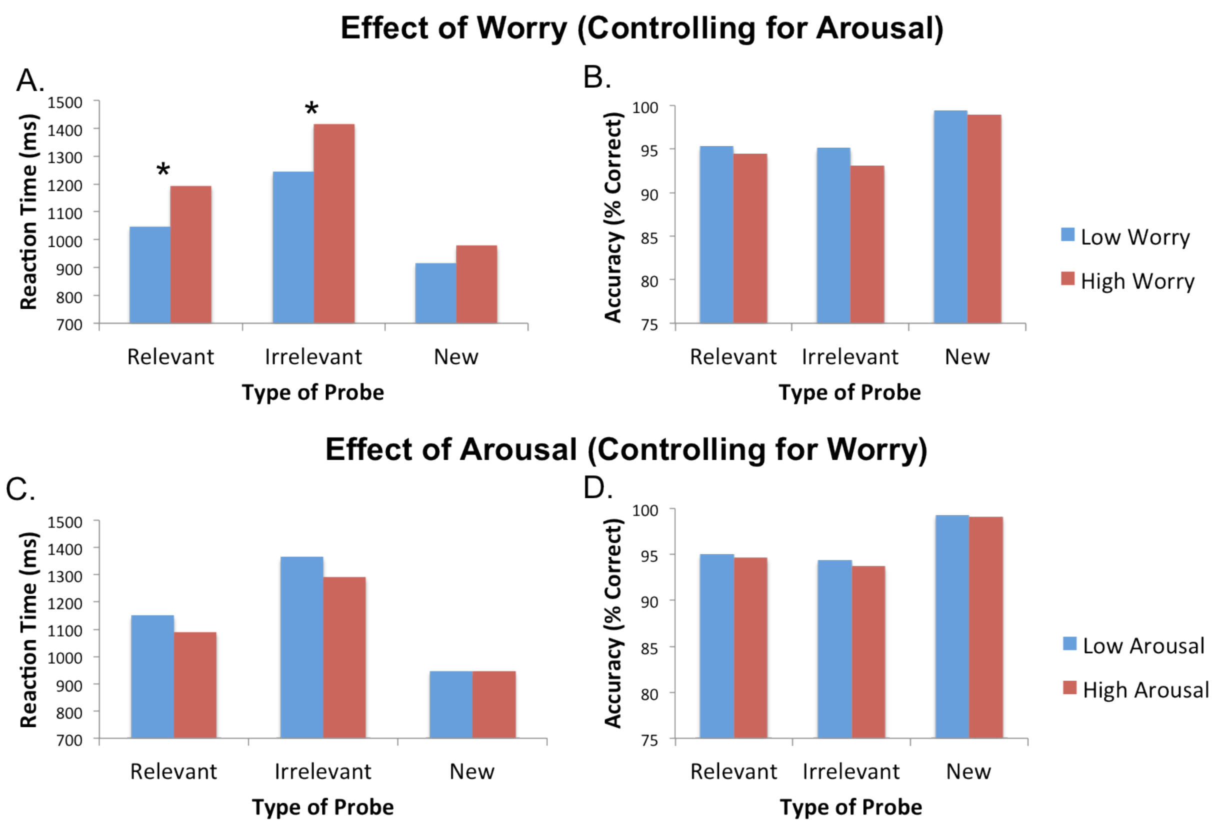
To test whether worry moderated the within-subjects effects of the ANOVA for accuracy and RT data, I followed the regression procedures outlined by Judd, McClelland, and Ryan (2008; see also Judd, Kenny, & McClelland, 2001). In these analyses, I controlled for the effects of anxious arousal and dysphoria levels as covariates following the procedure recommended by Yzerbyt, Muller, and Judd (2004). In addition, gender was also controlled for because women are more prone to anxiety than men (Seeman, 1997), and because gender was correlated with levels of worry in this sample, $r_{pb}(96) = .29$, $p < .001$. For graphical purposes the figures for this section depict levels of worry or anxious arousal at plus and minus 1 SD (e.g., high worry vs. low worry), though the analyses are done treating individual differences variables as continuous (Aiken & West, 1991).

Probe accuracy. Neither worry nor anxious arousal interacted with any of the within-subjects experimental manipulations for accuracy data, $F(1,90) < 2.28$, $p > .135$, and were not related to accuracies on any of the individual probe types collapsing across the other experimental manipulations, $F(1,90) < 2.36$, $p > .128$. Because accuracy was high across all conditions of the task, it is not surprising that the individual differences measures did not interact with any of the experimental effects. Furthermore, these results are consistent with the claim that anxiety is not usually associated with reduced processing effectiveness.

Probe RT. The main goal of this study was to test whether trait worry is related to RTs on a WM updating task requiring deletion and, if so, how. Because the predictions of the three hypotheses (persisting irrelevant thoughts, selection difficulty, and general slowdown) outlined earlier differed with respect to the effect of probe types, the analysis focused on the probe type × worry interaction.

As illustrated in Figure 2A, the interaction of probe type × worry was significant, $F(2,90) = 3.53$, $p = .031$, $\eta^2 = .07$. Further analysis indicated that trait worry was related to significantly longer RTs for relevant probes, $F(1,90) = 4.20$, $p = .043$, $\eta^2 = .04$, and for

Figure 2: Individual Differences Effects on Deletion Trials in Study 1



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

irrelevant probes, $F(1,90) = 4.37$, $p = .039$, $\eta^2 = .05$, but not to RTs for new probes, $F(1,90) = 1.12$, $p = .293$, $\eta^2 = .01$.

In addition, the effect of worry on irrelevant probes appeared to be stronger than on relevant probes (the difference between the model estimates for 1 SD below and above were 161 ms for relevant probes and 214 ms for irrelevant probes), which would provide support for the persisting irrelevant thoughts hypothesis. When the analysis focused only on relevant and irrelevant probes, however, the probe type x worry interaction was nonsignificant, $F(1,90) = 1.95$, $p = .166$, $\eta^2 = .02$. This nonsignificant interaction suggests that the relationship between worry and relevant probes was comparable to that between worry and irrelevant probes. This pattern of results appears to support the selection difficulty hypothesis, which states that worriers have difficulty regulating the contents of their WM, especially on a task requiring quick, controlled retrieval of relevant information. However, this lack of a significant interaction – hence, the support for the selection difficulty hypothesis – is weak because there was a tendency for irrelevant trials to be affected more. Trait worry did not interact with any of the other experimental manipulations (i.e. CSI, relevant list length and irrelevant list length), though there was a marginally significant interaction between irrelevant list length and worry, $F(1,90) = 3.37$, $p = .070$, $\eta^2 = .03$[2], such that the effect of worry was stronger for longer irrelevant lists. This finding is consistent with all three hypotheses, because longer irrelevant lists are more difficult to remove from mind and should be related to stronger source selection demands.

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[2] This effect was also observed for the apprehension subscale of the BAI, $F(1,90) = 6.21$, $p = .015$, $\eta^2 = .06$, and the word span data discussed below show the same effects for this measure. None of the other PSWQ effects were observed for BAI-apprehension in this study.

It is also important to note that, as shown in Figure 2C, the probe type × anxious arousal interaction was not significant, $F(2,90) = .85$, $p = .428$, $\eta^2 = .01$, controlling for levels of worry and dysphoria. This result provides further evidence that the crucial probe type × trait worry interaction effect was not due to any comorbid effects of anxious arousal or dysphoria.

Word Span Data

An ANOVA with one within-subjects factor, number of words (2, 4 or 6), was performed on the 10% of trials of the WM deletion task in which subjects recalled all words presented originally. This effect was significant, $F(1,95) = 321.46$, $p < .001$, $\eta^2 = .77$, revealing that accuracy decreased for trials with more words. Subjects recalled two words nearly perfectly ($M = 99.3\%$, $SE = .03\%$), and accuracy decreased for trials with four ($M = 86.9\%$, $SE = 1.0\%$) and six ($M = 64.3\%$, $SE = 1.8\%$) words.

None of the individual differences variables, including worry, were predictive of recall for trials with 2, 4 or 6 words, or accuracy aggregated across trials (see Table 1). For example, the correlation between PSWQ scores and aggregated free-recall accuracy was $r(94) = -.06$, $p = .89$, even though the reliability of the aggregated free-call accuracy was satisfactory (.79). These effects remain nonsignificant even when controlling for other mood variables. Thus, the word span data are consistent with Eysenck et al.'s (2007) suggestion that anxiety is not related to performance on WM span tasks in nonthreatening situations.

Discussion

There were three main goals of this research. The first goal was to examine a theorized relationship between trait anxiety and WM deletion and, if so, to test which of three hypotheses best explained this relationship. To this end, I did find that trait levels of worry were related to RTs on the deletion component of the updating task. These findings are novel in that they are the first to find a link between trait anxiety and WM updating in this particular context.

Furthermore, the effects observed for trait worry were consistent with the predictions of the selection difficulty hypothesis, with some provisos. Trait worry was related to performance on relevant and irrelevant probes, but not new probes, ruling out the general slowdown hypothesis. Additionally, the general slowdown hypothesis suggests that worry effects may increase proportionally with task difficulty. However, worry did not significantly interact with CSI or the list length manipulations (which had strong within-subjects effects), suggesting worry effects did not increase with task difficulty. Importantly, although the effect of worry was stronger for irrelevant probes (which would indicate support for the persisting irrelevant thoughts hypothesis), this difference was not significant, suggesting that the results of Study 1 supported the selection difficulty hypothesis. However, this relationship was approaching significance, which could suggest this study may have been underpowered to find this effect[3]. Therefore, although statistically the null hypothesis was supported in this study, a more rigorous test of whether the persisting irrelevant thoughts or the selection difficulty hypothesis best explains the relationship between worry and deletion is a focus in Study 2.

For the second goal, I tested whether anxiety would be related to performance on a WM span task that did not heavily rely on deletion. As in much of the previous

[3] Approximately 30 additional subjects are currently being run to clarify whether this interaction reaches statistical significance and to observe whether the effects of BAI-Apprehension converge more with the results for the PSWQ discussed here.

research on trait anxiety and WM updating, the relationship between anxiety and word span was absent. Neither worry nor anxious arousal was related to accuracy on the portion of the WM deletion task requiring subjects to simply recall words they previously memorized. These results serve to replicate previous research and confirm a claim of attentional control theory, that trait anxiety is not related to performance effectiveness on a measure of verbal WM span.

The third goal was to test whether the effects observed were for trait levels of worry rather than comorbid influences from anxious arousal or dysphoria. Trait worry was related to RTs on the WM deletion task, controlling for levels of anxious arousal and dysphoria, and these other mood variables were not related to performance on the WM task. Because this effect was observed only for trait worry controlling for other individual differences variables, these findings confirm that the effects of trait anxiety observed in this study reflected primarily trait worry rather than anxious arousal or dysphoria.

Chapter 3:

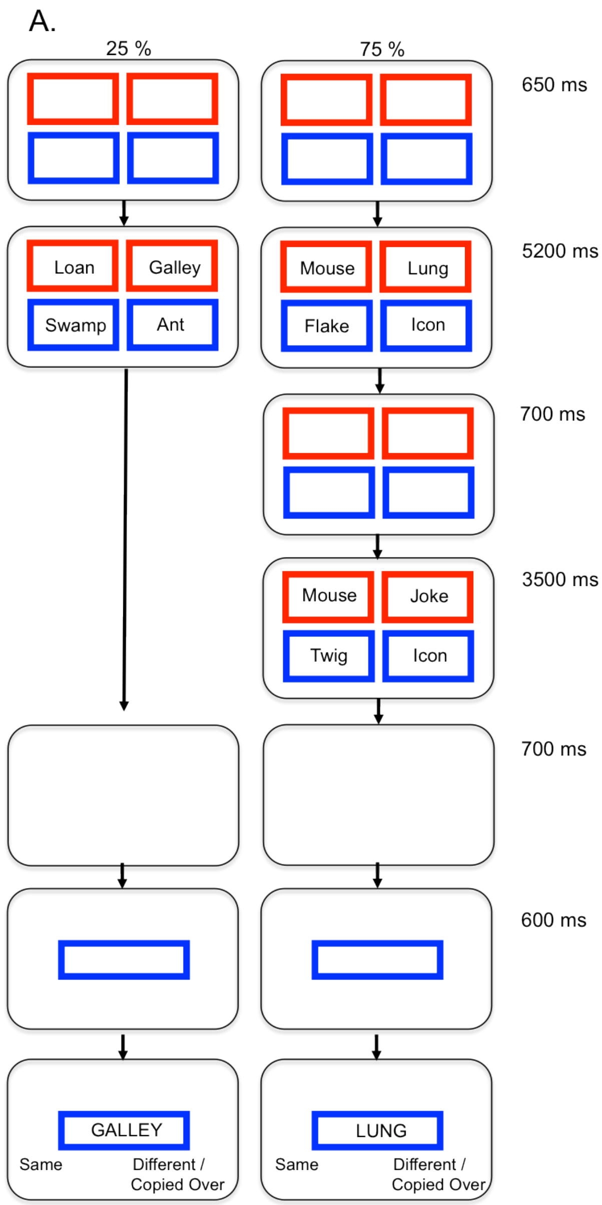
Study 2

Study 2 Introduction

Study 2 also addressed three main goals, corresponding to the goals of the first study. To address the first goal, a modified version of the WM task from Study 1 was implemented in Study 2. The WM task was altered for two reasons. First, some of the within-subjects experimental manipulations (i.e., CSI, list length) were not related to levels of worry, so the task was simplified on these aspects. Second, it was important to alter the task to more clearly discriminate between the predictions of the persisting irrelevant thoughts hypothesis and the selection difficulty hypothesis. Although the persisting irrelevant thoughts hypothesis predicts that worry affects processing of irrelevant information more strongly than relevant information (a trend that was observed in Study 1 but not statistically significant), and the selection difficulty hypothesis does not, it was important to compare these two hypotheses more directly in another context where they make different predictions.

In the WM deletion task used in Study 2 (see Figure 3), subjects memorized two lists of words, this time always with two words in each list. Afterward, 25% of trials were identical to those used in Study 1 (the left column of Figure 3a), except that new probes were not included in this task because they did not show any effects in Study 1. However, on 75% of trials (the right column of Figure 3a), after subjects memorized the first set of lists, they performed another memorization step that involved replacing two of the memorized words with two new words before being probed. In addition, only one CSI (600 ms) was used in the Study 2 task because there were no effects of CSI in Study 1, and this CSI is near, but not totally after, the end of the interval where large

Figure 3: Conditions of the WM Deletion Task Used in Study 2



B.

	One memorization phase (25%)	**Two memorization phases (75%)**		
Probe Source	**No-Update Probes**	**First Phase Probes**	**Second Phase Probes**	**Replaced Probes**
Relevant	SWAMP or ANT	ICON	TWIG	FLAKE
Irrelevant	LOAN or GALLEY	MOUSE	JOKE	LUNG

(A) The modified WM task used in Study 2. (B) The different probe types used in the WM task in Study 2. Relevant and irrelevant probes are shown providing the probe box was colored *blue*. They would be reversed if the probe box were red.

irrelevant lists are more easily removed (Oberauer, 2005). There were no free recall trials in Study 2.

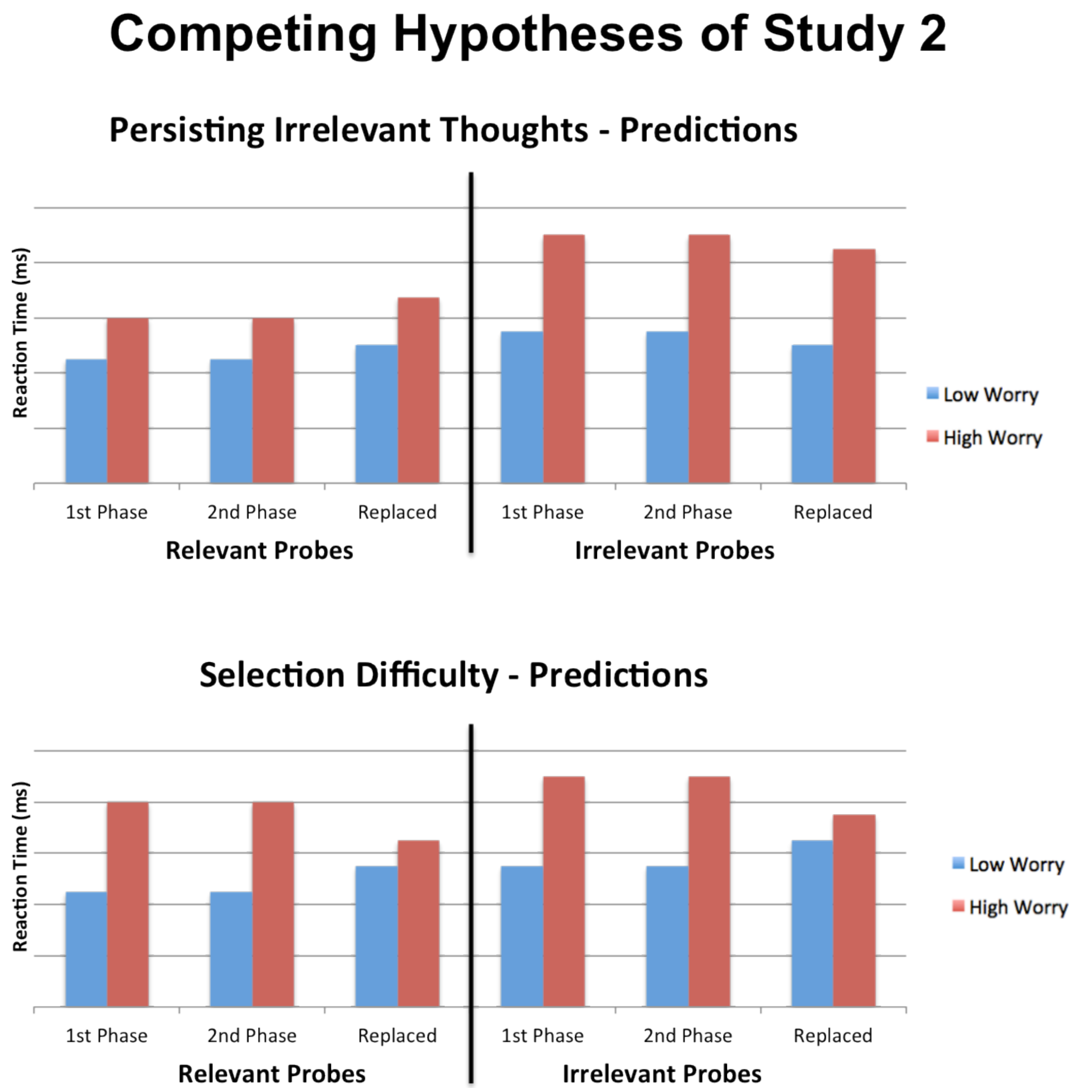
The changes to the WM deletion task resulted in 4 different types of probes, each of which could be from the relevant or irrelevant lists (see Figure 3b). The first type (Column 1 of Figure 3b) were probes for trials that did not have a memorization phase (no update probes). These probes acted as a test of replication and clarification for the effects observed in Study 1 (i.e., the overall effect of worry on relevant and irrelevant probes and the interaction between relevance and worry). There were also probes for words that were presented originally and presented again in the second memorization phase (first phase probes), and probes for words that were not presented originally but presented in the second memorization phase (second phase probes). These probes were also similar to those used in Study 1. Finally, the addition of the second memorization phase allowed a key trial type to be tested (examples are shown in the right column of Figure 3a and the far right column of Figure 3b): words that were originally presented in the relevant or irrelevant list, but were copied over during the second memorization step and probed afterward (replaced probes). It is important to note that although there are both relevant and irrelevant trial types for these probes (they could come from the colored list that ended up being relevant or irrelevant), these trials both required 'no' responses because they were copied over and were not actually part of the final remembered list.

The addition of the key trial type to the WM deletion task was particularly important because it allowed for a test that further distinguished the predictions of the selection difficulty hypothesis with those of the persisting irrelevant thoughts hypothesis. The persisting irrelevant thoughts hypothesis predicts that these trials are affected in trait worry. If removal of irrelevant information is related to trait worry, worriers are not able to efficiently remove these "replaced" words from mind before the probe phase, resulting in slower RTs when these words are probed. The selection difficulty hypothesis, however, predicts that these trials are *not* related to trait worry because worriers do not have difficulty removing information from mind. Rather, worriers are able to expel these irrelevant words from WM well before the final difficult selection step (when the probe box and subsequent word appear). The selection difficulty hypothesis suggests that when these words are probed, they will act more like the new probes in Study 1: words not part of the final memorization lists that were efficiently rejected.

Figure 4 displays the competing predictions of the persisting irrelevant thoughts and the selection difficulty hypotheses. Essentially, each hypothesis predicts that there will be an overall effect of worry on this task, and there will be one interaction between worry and a within-subjects manipulation (relevance x worry or probe type x worry) but not the other. As mentioned, the persisting irrelevant thoughts hypothesis predicts that irrelevant probes are affected more than relevant probes (i.e., a significant relevance x worry interaction), because worry is primarily related to processing irrelevant information. However, it does not predict that worry will affect the different probe types in different ways (i.e., a null probe type x worry interaction). Specifically, worry will be related to replaced probes. In contrast, the selection difficulty hypothesis predicts that both relevant and irrelevant probes are equally affected (i.e., a null relevance x worry interaction), but it does not predict that replaced probes will be affected like the other probe types (i.e., a significant probe type x worry interaction)

The second goal of Study 2 was to evaluate further the finding that trait anxiety was not related to performance on WM span tasks. In Study 1, there was no relationship between trait anxiety and simple word span. However, the study did not include a

Figure 4: Competing Hypotheses of Study 2



The competing hypothesis tested in Study 2. "High" and "Low" refer to the regression model predictions for plus or minus one standard deviation of BAI-Apprehension scores. The persisting irrelevant thoughts hypothesis predicts that all trial types will be affected, but these effects will be stronger for irrelevant probes (relevance x worry interaction). The selection difficulty hypothesis predicts relevant and irrelevant probes will be affected equally, but that the replaced probes will show no effect of worry (probe type x worry interaction).

complex span task like those used by Crowe et al. (2007), who found that worry was related to spatial but not verbal WM. In Study 2, the letter rotation span task (Shah & Miyake, 1996) and the reading span task (Daneman & Carpenter, 1980) were administered to measure spatial and verbal WM capacity respectively. In addition to an accuracy measure of WM span, I also measured the accuracy and RTs on the processing tasks within both of these complex span tasks (i.e., letter rotation, sentence reading) because the effect of worry might show up on these processing tasks (Visu-Petra et al., 2011).

Finally, as in Study 1, the third goal was addressed by controlling for levels of anxious arousal and dysphoria to ensure further that any observed effects are due to trait worry and not from comorbid anxious arousal or dysphoria levels.

Method

Unless otherwise noted, the methods and design for Study 2 are identical to Study 1.

Subjects

One hundred and ten undergraduate students (68 women and 42 men) participated in Study 2 for partial course credit.

Materials and procedure

The study took 90 minutes. Subjects performed the letter rotation span, the first two blocks of the modified deletion task, the reading span, the last two parts of the deletion task, and the questionnaires. Blocks of the deletion task were separated to give the subjects an opportunity to rest.

Questionnaires. In Study 2, levels of worry were measured with the apprehension subscale of the Beck's Anxiety Inventory (Beck et al., 1988), which had 9 items and 4 response levels per item[4]. Anxious arousal was measured with the anxious arousal subscale of the Beck's Anxiety Inventory (Beck et al., 1988), and dyspohria levels were measured with Beck's Depression Inventory (Beck & Steer, 1987).

Letter rotation span task. The letter rotation span task (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Shah & Miyake, 1996) is a measure of spatial WM capacity. In a given trial for this task, a subject was first shown a letter (*F*, *P*, or *R*) that was displayed normally or mirrored and was also rotated around its axis. The subject was instructed to say aloud whether the word was displayed normal or mirrored, and the experimenter recorded these responses[5]. Immediately after their response, the subject was shown a picture of an arrow in one of eight directions (up, down, left, right and the four diagonals) and instructed to remember the arrow. This process was repeated so that the subject remembered 2, 3, 4 or 5 arrows. After each trial was over, the subject responded by indicating which arrows were displayed on a paper and pencil answer sheet. Subjects were scored with one point per correct arrow that was identified in the correct serial order (Friedman & Miyake, 2005). Three trials were completed for each arrow length, resulting in 42 total arrows.

Reading span task. The reading span task (Daneman & Carpenter, 1980) measures verbal WM capacity and is very similar to the letter rotation span task. In each trial, participants read aloud a sentence (e.g., *Liquid is sharp and prickly*) and said aloud whether that sentence was true or false. Like the letter rotation span task, the

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[4] As in Study 1, levels of worry were also measured with the PSWQ. For some unknown reason, in Study 2 the PSWQ did not show as clear results as the apprehension subscale of the BAI. Differences between these measures are discussed in footnote 6 and in the General Discussion.

[5] This RT measure is not perfectly precise because the experimenter recorded subject's responses. Nevertheless, this is a fairly accurate measure of the processing component RT (Friedman & Miyake, 2004)

experimenter recorded responses to this processing task. After each sentence, subjects then memorized a subsequent target word. After 2, 3, 4 or 5 of the sentence/word pairs, subjects were cued to recall aloud all of the target words in correct serial order, using the word 'blank' to represent positions they have forgotten. Experimenters recorded subject's responses, and each subject's score was the total number of correctly recalled words, out of 42 total words (Friedman & Miyake, 2005).

WM deletion task. As in Study 1, all stimuli were drawn from the same list of English nouns, but the task had a few important changes. As shown in Figure 3, subjects saw four empty boxes (two red and two blue) for 650 ms., followed by the four initially presented words, displayed for 5.2 s total.

On 75% of trials, the trials requiring updates, the colored boxes were again shown without words for 700 ms, followed by another display of four words. Two of these words, one in each list, were new, and subjects were instructed to remember these words instead of the words that previously occupied their respective positions. The other two words that were not replaced were displayed again in their original position. Subjects had 3.5 s to memorize this final list. On the other 25% of trials, this updating phase was skipped. Therefore, the final list in subject's memory contained either two original words and two updated words (75%) or all four original words (25%).

Regardless of trial type, a blank screen was then displayed for 700 ms, followed by the cue for the relevant list (a red or blue box in the middle of the screen). After a 600 ms CSI, the probe word appeared in uppercase in the center of the colored box. Subjects were instructed to press the left button box button for probes that appeared in the same color box as displayed in the final list (relevant probes), and the right button box button for words that were either displayed in the irrelevant color (irrelevant probes) or words that were part of the initial display that were copied over (replaced probes).

Data Analysis

As in Study 1, accuracy and RT data from the WM deletion task were analyzed with RTs greater than 5 s removed (.2% of the total trials), and RT data were analyzed for correct trials only. A 2.5 SD trimming was performed on RT data as well. Arcsine (accuracy) and logarithmic (RT) transformations were again performed, but these analyses also revealed the same pattern of results, so the nontransformed data are reported here.

Results

Questionnaire Data

The descriptive statistics and correlations for the questionnaires used in Study 2 are summarized in Table 3. Levels of trait worry again correlated with anxious arousal and dysphoria, suggesting the need to statistically control for these comorbid mood variables.

WM Deletion Task: Experimental Effects

There were 4 different types of probes used in Study 2 (see Figure 3), each of which could be from the relevant or irrelevant lists. The probe accuracy and RT data were subjected to one ANOVA with 2 within-subjects variables: relevance (the probe word appeared from the relevant or irrelevant list) and probe type (no-update, first-phase, second-phase, or replaced). Mean accuracies (and RTs) for each condition are reported in Table 4.

Probe RT. As in Study 1, subjects responded more quickly to relevant probes than irrelevant probes, $F(1, 109) = 197.58$, $p < .001$, $\eta^2 = .64$. There was also a main effect of probe type, $F(3, 109) = 9.29$, $p < .001$, $\eta^2 = .08$, and an interaction between probe type and relevance, $F(3, 109) = 26.77$, $p < .001$, $\eta^2 = .20$. This interaction was driven by the fact

Table 3: Descriptive Statistics and Correlations of Individual Differences Questionnaires and the WM Span Tasks in Study 2

							Correlation w/ questionnaires		
Measure	Mean	SD	Range	Skew-ness	Kurtosis	Reliability	Worry	Arousal	Dysphoria
Worry (BAI-Apprehension)	4.25	3.51	0 – 14	1.02	0.56	.76	-	.72*	.60*
Arousal (BAI-Arousal)	4.24	4.20	0 – 19	1.08	0.85	.82		-	.62*
Dysphoria (BDI)	10.38	9.06	0 – 60	1.88	7.18	.89			-
Letter rotation span recall	23.21	6.56	12 – 40	0.51	-0.23	.78	-.12	-.13	-.17#
Reading span recall	21.91	5.39	10 – 38	0.59	0.41	.76	.10	.02	.06
Letter rotation span RT	1702	333	1101-3042	1.63	4.07	.86	-.04	-.10	-.13
Reading span RT	3247	369	2389-4899	0.99	1.80	.94	.03	-.01	.10
Letter rotation span accuracy	0.94	0.09	.54 - 1.00	-2.42	6.69	.89	.02	.04	.05
Reading span accuracy	0.97	0.03	.85 – 1.00	-1.39	3.22	.26	.13	.20*	.20*
Letter rotation span composite	0.00	1.53	-7.42–3.34	-1.36	4.77	N/A	-.09	-.13	-.16
Reading span composite	0.00	1.75	-5.05-5.38	0.11	0.83	N/A	.15	.12	.20*

Note: Reliability was calculated using Cronbach's Alpha. (# indicates marginally significant correlation $p < .10$, * indicates a significant correlation, $p < .05$). RTs and accuracy for the letter rotation and reading span refer to RT and accuracy for the processing task. Composite measures for letter rotation and reading span rows are summed z-scores for span performance, RT for the processing component and accuracy for the processing component.

Table 4: Means for the Within-Subject Factors of the Working Memory Task in Study 2

	No-Update		First-Phase		Second-Phase		Replaced	
Source	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Accuracy								
Relevant	94.3	.6	92.3	1.1	90.7	1.2	90.4	1.5
Irrelevant	93.4	.9	91.6	1.0	91.1	1.0	93.6	1.1
Reaction Time								
Relevant	1362	39	1472	47	1399	49	1534	57
Irrelevant	1526	41	1635	47	1656	47	1551	53

Note: RTs (in milliseconds) and accuracies (in percent correct) for all conditions that relevant replaced probes were more difficult than the other type of relevant probes (no-update being the easiest), whereas irrelevant replaced probes were easier than most of the other irrelevant probes (no-update responses were slightly faster). This finding makes sense because relevant replaced probes likely had more interference (they were part of the relevant list but were copied over and became irrelevant) whereas irrelevant replaced probes triggered a 'no' response for multiple reasons (they were copied over and from the irrelevant list).

Probe accuracy. The accuracy data showed similar overall patterns to the RT data. Although there was no main effect of relevance, $F(1, 109) = 197.58$, $p < .001$, $\eta^2 = .64$, there was a main effect of probe type, $F(3, 109) = 197.58$, $p < .001$, $\eta^2 = .64$, and an interaction between probe type and relevance, $F(3, 109) = 197.58$, $p < .001$, $\eta^2 = .64$. These effects were generally in the same direction as the RT data; with relevant replaced probes being the most difficult of the relevant probes and irrelevant replaced probes having the best accuracy compared to other irrelevant probes.

WM Deletion Task: Effects of Trait Anxiety

As in Study 1, I tested whether worry moderated the within-subjects effects of the ANOVAs by following the regression procedures outlined by Judd et al. (2008). I again controlled for the effects of anxious arousal and dysphoria levels. In this study, levels of worry did not correlate with gender, $r_{pb}(110) = .10$, p = .31, so gender was not included as a covariate in Study 2 (though it did not affect the patterns of results if it was included). Like Study 1, for graphical purposes, the figures for this section depict levels of worry (or anxious arousal) at plus and minus 1 SD (following Aiken & West, 1991), though the analyses are done treating individual differences variables as continuous.

The trial types for Study 2 were separated for analysis of individual differences effects. First, the no-update probes were analyzed separately because they acted as a test of replication of the effects of Study 1. Second, the final three probe types were analyzed together to see if the results for these trial types supported the persisting irrelevant thoughts or selection difficulty hypotheses (see below).

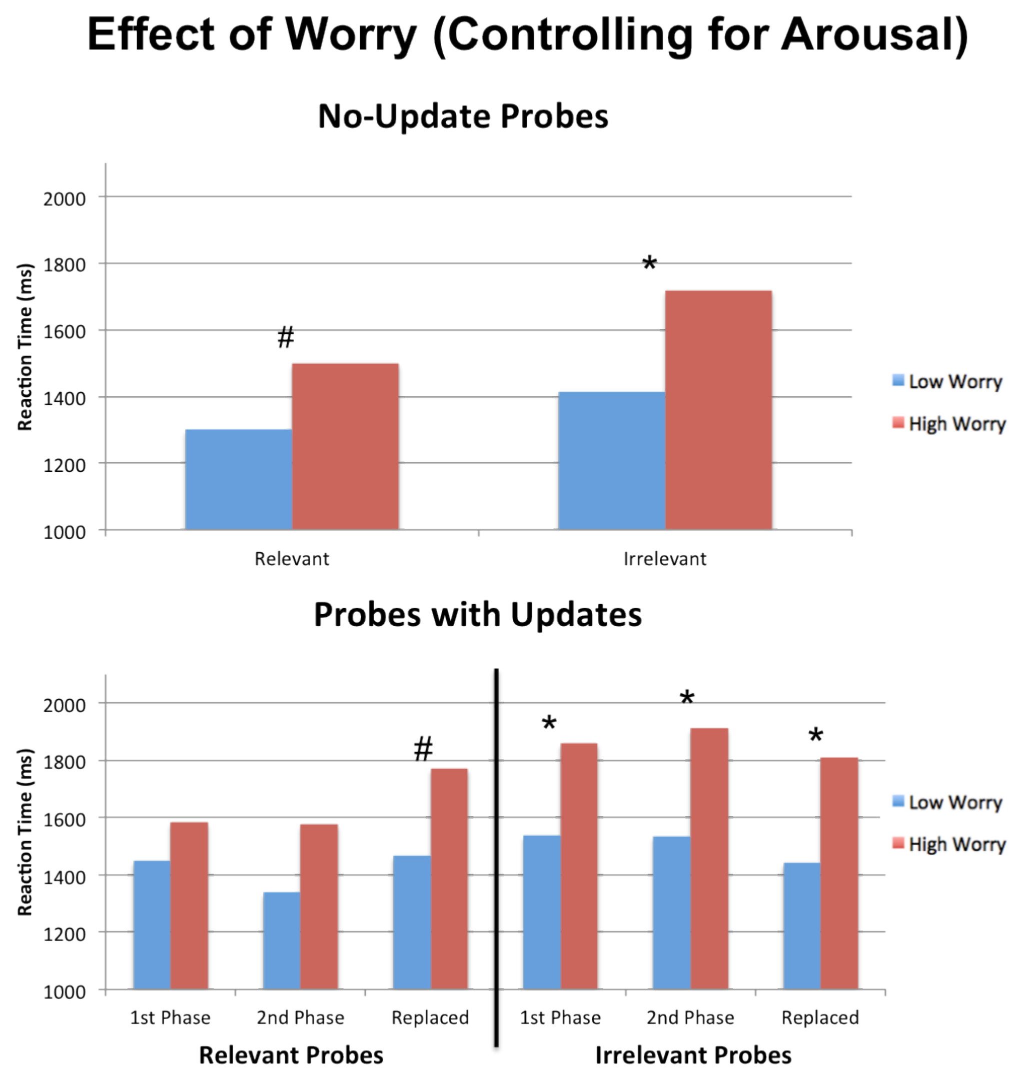
Trials with no updates. As mentioned, the no-update provided a test of replication and clarification for the individual differences effects observed in Study 1.

Probe RT. As shown in Figure 5, higher levels of worry, controlling for the other mood variables, were related to longer RTs to no-update probes overall, $F(1, 105) = 4.56$, $p = .035$, $\eta^2 = .04$. Further analyses revealed that, when analyzed separately, this relationship was marginally significant for relevant no-update probes, $F(1, 105) = 2.87$, $p = .093$, $\eta^2 = .03$, and significant for irrelevant no-update probes, $F(1,105) = 6.07$, $p = .015$, $\eta^2 = .05$.

Important to note, worry did interact with relevance on these trials, $F(1, 105) = 4.31$, $p = .040$, $\eta^2 = .04$, revealing that the effect of worry were significantly larger for irrelevant compared to relevant no-update probes. This trend was observed in Study 1, but was not significant. The significant effect observed in this study provides some support for the persisting irrelevant thoughts hypothesis, which predicts that irrelevant information is affected more in worry, and suggests that Study 1 may have in fact been underpowered to observe this relationship.

Finally, as observed in Study 1, levels of anxious arousal were not related to overall RT, $F(1, 105) = .01$, $p = .913$, $\eta^2 < .01$, or predictive of RTs for the individual trial types.

Figure 5: The Effects of Worry on Deletion Trials in Study 2



The effect of worry on probe RTs in Study 2. "High" and "Low" refer to the regression model predictions for plus or minus one standard deviation of BAI-Apprehension scores (* indicates significant effect p < .05, # indicates marginally significant effect p < .10).

Probe accuracy. As in Study 1, worry was not predictive of overall accuracy for no-update probes, $F(1, 105) = .74$, $p = .390$, $\eta^2 = .01$, or for relevant no-update probes, $F(1, 105) = 0.13$, $p = .718$, $\eta^2 < .01$, or irrelevant no-update probes, $F(1, 105) = 2.30$, $p = .133$, $\eta^2 = .02$, individually. Similarly, levels of anxious arousal were not predictive of accuracy for the no-update probes overall, $F(1, 105) = .43$, $p = .514$, $\eta^2 < .01$, and were not predictive of either of the individual trial types.

Trials with updates. The main goal of Study 2 was to test whether the effects of trait worry on this task would support the persisting irrelevant thoughts hypothesis or the selection difficulty hypothesis. The persisting irrelevant thoughts hypothesis would be supported by a significant relevance x worry interaction and a nonsignificant interaction between probe type x worry (i.e., replaced probes are affected in worry). The selection difficulty hypothesis, however, would be supported if there was no significant interaction between relevance and worry, but a significant probe type x worry interaction (specifically, replaced probes are not affected in worry).

Probe RT. The RT effects for trials with updates are consistent with the persisting irrelevant thoughts hypothesis. As shown in Figure 5, worry was related to significantly longer RTs for these probe types overall, $F(1, 105) = 4.20$, $p = .043$, $\eta^2 = .04$. Individually, significant effects of worry were observed for irrelevant first-phase probes, $F(1, 105) = 5.17$, $p = .025$, $\eta^2 = .05$, irrelevant second-phase probes, $F(1, 105) = 7.47$, $p = .007$, $\eta^2 = .07$, and irrelevant replaced probes, $F(1, 105) = 5.25$, $p = .024$, $\eta^2 = .05$ (there was also a marginally significant effect for relevant replaced probes, $F(1, 105) = 3.16$, $p = .078$, $\eta^2 = .03$).

Importantly, there was an interaction between relevance and worry, $F(1, 105) = 13.49$, $p < .001$, $\eta^2 = .11$, such that the worry effect was stronger for irrelevant probes than relevant probes. In addition, there was no evidence for a significant probe type x worry interaction, $F(2, 105) = 1.25$, $p = .503$, $\eta^2 = .02$, suggesting that worry was related to performance on all probe types equally. These results provide clear support for the persisting irrelevant thoughts hypothesis[6].

Levels of anxious arousal were not predictive of RT overall, $F(1, 105) = .02$, $p = .89$, $\eta^2 < .01$, or for the individual trial types.

Probe accuracy. Worry was not related to accuracy overall, $F(1, 53) = .01$, $p = .932$, $\eta^2 < .01$, or for any of these individual trial types. Similarly, levels of anxious arousal (and dysphoria) were not related to overall accuracy, $F(1, 105) = .03$, $p = .957$, $\eta^2 < .01$, and did not predict RT on any of the individual trial types. Thus, as in Study 1, the effect of worry was observed only for the RT data, consistent with the processing efficiency theory (Eysenck et al., 2007).

Complex Span Tasks

Descriptive statistics for the complex span measures used in Study 2 are displayed in Table 3. Levels of trait worry did not correlate with either spatial or verbal span. Worry was also not related to spatial span, $F(1, 105) = .03$, $p = .852$, $\eta^2 < .01$, or verbal span, $F(1, 105) = 2.01$, $p = .160$, $\eta^2 = .02$, controlling for anxious arousal and dysphoria. These results provide more support for the claim that trait anxiety is not related to WM span (Eyesenck et al., 2007) in nonthreatening situations.

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[6] If the PSWQ is used instead to measure worry in these analyses, the relevance by worry interaction remains significant, $F(1, 105) = 6.44$, $p = .013$, $\eta^2 = .06$, the probe type by worry interaction remains not significant, $F(1, 105) = .45$, $p = .630$, $\eta^2 = .01$, and the results for the complex span tasks discussed later are the same, but the overall effects for worry were not observed for this measure, $F(1, 105) = .33$, $p = .569$, $\eta^2 = .01$.

Analyses of the processing component of both tasks revealed the same results. Worry was not predictive of RT for the processing component of the spatial span, $F(1,105) = 0.48$, $p = .489$, $\eta^2 < .01$, or verbal span, $F(1,105) = 0.08$, $p = .779$, $\eta^2 < .01$, tasks. In addition, worry was not related to accuracy for the processing component of the spatial span task, $F(1,105) = 0.78$, $p = .381$, $\eta^2 = .01$, or verbal span task, $F(1,105) = 0.01$, $p = .914$, $\eta^2 < .01$. Finally, a composite score of performance on the WM span tasks was calculated to make sure there were no speed-accuracy tradeoffs. This composite score was calculated by computing the sum of the z-scores for span accuracy, processing component RT, and processing component accuracy for each span task. Worry again was not related to this composite measure for the spatial span task, $F(1,105) = 0.14$, $p = .706$, $\eta^2 < .01$, or verbal span task, $F(1,105) = 0.90$, $p = .344$, $\eta^2 = .01$.

As Table 3 indicates, levels of arousal were correlated positively with processing speed accuracy for the reading span task, $r(110) = .20$, $p = .03$, but this relationship was not significant controlling for the other mood variables, $F(1, 105) = 2.36$, $p = .127$, $\eta^2 < .02$. Importantly, these results provide more evidence that trait worry is not related to WM capacity, even when measures of performance efficiency are measured.

Discussion

The first goal of Study 2 was to confirm that worry was related to WM updating and, if so, test which of two hypotheses best explained this relationship. These results again show that trait worry is related to performance efficiency on a WM updating task requiring deletion. Worry was related to overall RTs on trials both with and without a second memorization phase.

Additionally, the findings of this study support the persisting irrelevant thoughts hypothesis. As predicted, worry was related more strongly to processing irrelevant information (relevance x worry interaction), for both no-update probes and probes on trials with updates. The most important trial types in this study were replaced probes, where predictions for the selection difficulty and persisting irrelevant thoughts hypotheses also differed. The selection difficulty hypothesis predicted that these trials would not be related to levels of worry because worriers would be able to expel irrelevant words from WM well before the final difficult selection step. However, this is not what was observed. Consistent with the persisting irrelevant thoughts hypothesis, trait worry was related to performance on these trial types as it was on all other trials of the WM deletion task (i.e., there was no interaction between probe type and worry).

For the second goal of Study 2, I examined whether worry would be related to performance on complex span tasks. Like Study 1, and most previous research on anxiety and WM span, levels of worry (and anxious arousal) were not related to overall performance on the span task. Furthermore, when I analyzed the processing component task data, I did not find that worry was related to any aspect of the task, even when creating a composite of performance on both span and processing task measures. These results are unlike those found by Visu-Petra et al., 2011, who found a link between anxiety and processing task RT, but in that study the authors used young children as subjects, who may be affected by trait anxiety and worry differently than young adults.

To address the third goal, the effects observed in Study 2 were again observed for levels of trait worry rather than anxious arousal, which, like Study 1, did not predict performance on any component of the WM deletion or WM span tasks. Again, because effects were observed only for trait worry, controlling for other individual differences variables, these findings confirm that the effects of trait anxiety observed in this study were due to trait worry rather than anxious arousal or dysphoria.

Chapter 4:

General Discussion

General Discussion Introduction

In this research, I evaluated attentional control theory's hypothesis that WM updating is spared in trait anxiety by decomposing WM updating and trait anxiety into their component parts. The three goals of these studies were to observe a link between trait anxiety and WM deletion, test whether anxiety was related to updating tasks that do not heavily rely on deletion, and show that trait worry, rather than comorbid anxious arousal or dysphoria, best explained these effects. The two studies reported in this thesis provided clear evidence regarding each of these goals.

Anxiety and WM Updating

The first goal was addressed by implementing two WM deletion tasks requiring effective removal of irrelevant information, and measured individual differences in trait worry, anxious arousal, and dysphoria. In both studies, trait worry was related to performance on many types of trials of this task. These findings are novel because the relationship between trait anxiety and WM deletion has never been tested in this context. Additionally, because the stimuli used in both of these tasks were of neutral emotional valence, these results suggest that high worrisome individuals show impairments with WM deletion even when they are not currently threatened. High trait worriers are more likely to worry, but they were not necessarily worrying more than low trait worriers in this study. In fact, the specificity of the effects in these two studies (i.e., worry was related to RT most of the deletion task trials, but not to performance on any WM span trials or new probes from Study 1) suggests that worries were not responsible for these observed effects, since it is unlikely worriers were worrying on some trials but not others.

To understand the mechanisms behind the worry-WM deletion association, I tested three different hypotheses to see which best predicted the observed effects. The results of these two studies suggest that the persisting irrelevant thoughts hypothesis best accounted for these results. This hypothesis proposed that trait worriers have a general difficulty removing irrelevant information from mind. In both studies, trait worry was related most strongly to trials where subjects had to respond to words that were from newly irrelevant lists. In Study 1, this relationship was observed but not significant. However, Study 2 had a simpler design (i.e., there were no CSI or list length manipulations) and was more powerful given the larger number of subjects. Moreover, in Study 2, worry was related to RTs on trials responding to words that should have been removed from mind early in each trial (i.e., replaced probes). Finally, in contrast to many of the other trials in these studies, worry was not related to processing efficiency for probes were not previously memorized (i.e., new probes in Study 1), and worry effects did not increase proportionally with task difficulty, suggesting the effects of worry on these tasks did not represent a broad impairment (as proposed by the general slowdown hypothesis), but rather a specific difficulty removing irrelevant information from mind.

This relationship sheds light on why worries are characterized as uncontrollable, unconstructive repetitive thoughts (Ehring & Watkins, 2008; Watkins, 2008). Worriers simply have difficulty removing irrelevant information from WM, and this problem manifests as chronic worry because when they come across negative, irrelevant thoughts, they cannot efficiently remove them from mind. Furthermore, the results of these studies suggest that the effects of persisting irrelevant thoughts apply to not only irrelevant information, but also to relevant information. Processing of relevant information during deletion was impaired as well in these tasks, suggesting worriers have trouble managing relevant information (e.g., productive, relevant thoughts) when they are in the process of, or immediately after, removing irrelevant information from mind.

The second goal of this research was to evaluate previous, and sometimes conflicting, results regarding whether anxiety is related to performance on WM span tasks. Previous research has equated performance on these tasks to WM updating, but they are not identical because WM span tasks do not have strong within-trial deletion components. In these two studies, both simple (Study 1) and complex (Study 2) measures of WM span, and both spatial and verbal WM span (Study 2) were tested to see if trait worry was in fact related to these types of WM tasks as well. In both studies, there was no evidence for an association between trait anxiety and WM span performance.

These findings are consistent with much of the initial research on trait anxiety and WM updating summarized in Eysenck et al. (2007). The results of both studies suggest that there is no link between trait anxiety and WM span in nonstressful situations. This remained true even when considering measures of RT and accuracy on the processing component segments of the complex span tasks, which had been linked to trait anxiety in children (Visu-Petra et al., 2011). Therefore, like the studies summarized by Eysenck et al. (2007), I also conclude that anxiety is not related to performance on measures of WM span.

Taken together, these results suggest that trait anxiety – specifically, worry – is significantly related to difficulties in WM updating. Updating is impaired in trait anxiety, but this was only made clear once a task with within-trial removal of irrelevant information was implemented. Trait worry is related to removing irrelevant information from mind on a task that requires deletion, but worry and anxious arousal are not related to performance on other types of updating tasks.

It is important to note that the measure of worry used in Study 1 and Study 2 differed (in Study 1 worry was measured with the PSWQ, but it was measured with the apprehension factor of the BAI in Study 2). Trait worry and apprehension are synonymous (Engels, Heller, Mohanty, Herrington, Banich, Webb, & Miller, 2007; Nitschke, Heller, Imig, McDonald, & Miller, 2001), and though the PSWQ is more often used to measure this construct in the relatively few studies on worry and cognition (Engels et al., 2007; Snyder, Hutchison, Nyhus, Curran, Banch, O'Reilly, & Munakata, 2010), it is unclear why the two measures did not show identical effects in both studies. However, the measures did not totally diverge. Each measure was related to some similar effects for the deletion tasks used in both studies (the irrelevant list length x worry interaction in Study 1, and both the relevance x worry and null probe type x worry interaction in Study 2). Additionally, neither measure was related to performance on the span measures in either study and these measures correlated highly in both studies, $r(96) = .57$, $p < .01$ (Study 1) and $r(110) = .56$, $p < .01$ (Study 2). Twenty to thirty subjects are being added to both studies to see if these measures show more converging results.

Worry vs. Other Mood Variables

The final goal was to decompose trait anxiety and show that the trait worry subcomponent of anxiety was related to the updating impairments observed in this research, rather than anxious arousal. In both studies, trait worry predicted performance on the WM deletion task even after controlling for the influences of anxious arousal. Anxious arousal, however, was not related to performance on any of the tasks in this research. These findings make sense because worry, the thought-based component of anxiety characterized by uncontrollable irrelevant thoughts, is a more likely candidate to be related to WM processing than the more physiological, mood-based, component of anxiety: anxious arousal.

In addition to controlling for the influences of anxious arousal, I also demonstrated that these effects were independent of the effects of dyspohria. Levels of depression and trait dyphoria have also been linked with performance on executive function tasks (Altamirano et al., 2010; Gotlib & Joormann, 2010). However, levels of dysphoria are often not controlled for in research on trait anxiety and executive functioning (Calvo et al; 1992; Crowe et al; 2007), even though they are highly comorbid (Mineka et al., 1998). Nevertheless, in this research trait worry was related to WM deletion, and this relationship was independent of any influence of dysphoria. Thus, it can be concluded that trait worry is related to WM deletion, and that there is no evidence that this is also the case for anxious arousal and dysphoria.

Revisiting Attentional Control Theory

The results of these studies suggest that the claims made by attentional control theory may need to be revised in some important ways. This research showed that trait worry, and therefore anxiety, is in fact related to performance on WM updating tasks in nonthreatening situations. Previous research has focused solely on measures of WM span, which do not heavily rely on deletion. However, trait worry is related to removing irrelevant information from WM. Given these findings, the claims of attentional control theory should incorporate the idea that, in nonthreatening situations, anxiety is not related to WM span, but is related to WM deletion processes.

Although attentional control theory does claim that worry is responsible for the link between trait anxiety and executive functioning (Eysenck et al., 2007), their explanation was not applicable to this study. Attentional control theory assumes that the effects of anxiety on processing efficiency are a consequence of worrisome thoughts consuming WM resources and causing auxiliary processing resources to be recruited to minimize the anxiety state (Eysenck et al., 2007). Subjects in this task, however, were not necessarily worrying; they simply had tendencies to be worriers. This difficulty removing irrelevant information at a trait level suggests that worries alone do not cause these effects. Rather, worriers may be different neurologically (structurally or functionally) in areas related to WM updating and possibly elsewhere.

The methods applied in this research may be relevant for other aspects of executive functioning as well. Other attentional control theory hypotheses may also need to be retested to address how exactly worry relates to inhibition and shifting – the two aspects of executive functioning that Eysenck et al. (2007) claim to be impaired in anxiety – because the existing explanations may not be sufficient. Furthermore, to find effects in these studies, it was crucial to decompose both constructs in question, anxiety and WM updating, to narrow down the source of their association. This should be done in the domains of inhibition and shifting as well to help make attentional control theory more precise and to better characterize the relationship between anxiety and these other executive functions.

Limitations and Qualifications

The finding that trait worry is related to selection difficulty during WM deletion is novel, but it does come with some qualifications. First, these effects are for sub-clinical levels of worry, anxious arousal, and dysphoria. The effects of these mood variables may look different if examined at the clinical level. Additionally, this research focused on trait levels of worry and anxious arousal rather than state levels, which may have different relationships to executive functioning. Nevertheless, the worry effects observed in these studies were strong enough to be seen for sub-clinical, trait, worriers in nonstressful situations, when they were not necessarily worrying, implying that the link between worry and WM deletion is relatively strong.

In this study, worry was related to WM updating, but in other domains or situations the opposite could be true. For example, when threatening stimuli are implemented on executive function tasks like this one, physiological variables may play a much larger role. In cases like this, anxious apprehension may in fact be related to performance efficiency (e.g., faster responses to threatening words regardless of relevance). Anxiety is often referred to as one construct, but the findings of these studies provide more evidence that it is more complex than that, and subtypes are important to consider when attempting to observe a link like this one (Heller & Nitschke, 1998).

Concluding Remarks

Based on the findings of this research, some of the claims of attentional control theory should be reevaluated. Namely, the results of these studies suggest that anxiety (specifically, worry) is related to WM updating processes in non-threatening situations. Previous research had focused solely on WM span tasks, which do not appear to be related to trait anxiety. However, WM updating is complex, and when the right components are tested, the relationship between anxiety and updating is apparent. Furthermore, trait worry was independently responsible for the relationship between anxiety and updating, but not in the way Eysenck et al. (2007) propose. This research provided support for the idea that worry is related specifically to removing irrelevant information from WM during deletion. Future research should incorporate decomposition of both anxiety and the construct in question in pursuit of refining theories about the relationship between anxiety and updating as well as the larger connection between anxiety and executive functions.

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Appendix A

Appendix A: Summary of Within-Subjects ANOVAs for Study 1

Variable	Accuracy $F(df)$	η^2	Reaction Time $F(df)$	η^2
Probe	82.82 (2, 95)*	.466	145.06 (2, 95)*	.064
CSI	< .01 (1, 95)	< .001	499.54 (1, 95)*	.826
Relevant Length	114.81 (1, 95)*	.547	514.15 (1, 95)*	.844
Irrelevant Length	31.26 (1, 95)*	.248	77.48 (1, 95)*	.449
Probe * CSI	2.79 (2, 95)	.028	53.48 (2, 95)*	.360
Probe * Relevant Length	26.89 (2, 95)*	.221	67.98 (2, 95)*	.417
Probe * Irrelevant Length	18.22 (2, 95)*	.161	11.63 (2, 95)*	.109
CSI * Relevant Length	14.19 (1, 95)*	.130	98.65 (1, 95)*	.509
CSI * Irrelevant Length	10.97 (1, 95)*	.161	19.14 (1, 95)*	.168
Relevant Length * Irrelevant Length	11.06 (1, 95)*	.104	0.40 (1, 95)	.004
Probe * CSI * Relevant Length	12.18 (2, 95)*	.114	23.20 (2, 95)*	.196
Probe * CSI * Irrelevant Length	11.61 (2, 95)*	.109	4.76 (2, 95)*	.048
Probe * Relevant Length * Irrelevant Length	4.10 (2, 95)*	.041	13.56 (2, 95)*	.125
CSI * Relevant Length * Irrelevant Length	6 .89 (1, 95)*	.068	3.20 (1, 95)	.033
Probe * CSI * Relevant Length * Irrelevant Length	7.95 (2, 95)*	.077	2.59 (2, 95)	.026

Note: * indicates significant effect