THE EFFECT OF UNCERTAINTY ON THE MAGNITUDE OF ERROR-RELATED BRAIN ACTIVITY IN ANXIOUS PEOPLE DURING A REINFORCEMENT LEARNING TASK

by

Emily M. Stanley

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology

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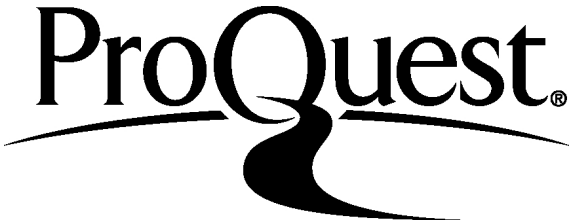

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Approved: _____
Robert F. Simons, Ph.D.
Chair of the Department of Psychological and Brain Sciences

Approved: _____
George H. Watson, Ph.D.
Dean of the College of Arts and Sciences

Approved: _____
James G. Richards, Ph.D.
Vice Provost for Graduate and Professional Education

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: _____

Robert F. Simons, Ph.D.
Professor in charge of dissertation

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: _____

Adele M. Hayes, Ph.D.
Member of dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: _____

James Hoffman, Ph.D.
Member of dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: _____

Rebecca Compton, Ph.D.
Member of dissertation committee

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ABSTRACT

Numerous studies have shown that anxious people produce larger Error-Related Negativity (ERN) than non-anxious people when making mistakes. However, this enhancement was not observed in several recent studies in people with Obsessive-Compulsive (OC) symptoms during tasks that require the trial and error learning of stimulus-response relationships. The present set of experiments explore the hypothesis that people with OC symptoms are uncertain that they have correctly learned the stimulus-response mappings in these tasks. This uncertainty results in producing a smaller ERN than they otherwise might in a more straight-forward and more commonly used response conflict task. Additionally, the present experiments explore whether worriers, who have been shown to have enhanced ERNs on response conflict tasks, show the same decreased ERN during learning tasks as people with OC symptoms. The results of Experiment 1 revealed that people with OC symptoms produce smaller ERNs during a learning task than during a typical response conflict task. No difference in ERN amplitude, however, was found for worriers. Additionally, only the participants with OC symptoms reported less cognitive confidence and more uncertainty about their responses during the learning task than during the response conflict task. Experiment 2 aimed to increase feelings of uncertainty about the task performance in non-anxious people and Experiment 3 aimed to decrease uncertainty about task performance in participants with OC symptoms. However, both of these manipulations were unsuccessful. Overall, the findings from these three studies provide only modest support for the hypothesis that participants with OC symptoms

feel more uncertain about the accuracy of their responses during learning tasks and there is no support for the hypothesis that their uncertainty is related to smaller ERNs. It should be noted that this effect appears to be specific to people with OC symptoms and does not generalize to people with anxiety more broadly.

Chapter 1

INTRODUCTION

The error-related negativity (ERN), also known as the Ne, is a response-locked component of the event-related potential (ERP) observed when people make slip mistakes (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Coles, Meyer, & Donchin, 1990). It is a negative deflection that begins at the time that an incorrect response is initiated, and peaks about 50 ms after response execution (Hajcak, Franklin, Foa, & Simons, 2008). The ERN is maximal at frontocentral recoding sites and has been observed when errors were made across several different stimulus and response modalities (Bernstein, Scheffers, & Coles, 1995) suggesting that it is capturing the activity of a general response monitoring system. The amplitude of the ERN is also modulated based on the significance of an error, with higher-stakes errors prompting larger ERNs (Hajcak, Moser, Yeung, & Simons, 2005).

Source localization of the ERN using EEG methods is consistent with a generator in the anterior cingulate cortex (ACC; Holroyd, Dien, & Coles, 1998; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). Other studies of error processing have supported that localization using different methodologies (intracerebral recording - Brázdil, Roman, Daniel, & Rektor, 2005; fMRI - Kiehl, Liddle, & Hopfinger, 2000; MEG - Miltner et al., 2003).

During the past decade, researchers have become interested in examining the ERN in a variety of psychopathologies (Simons, 2010; Olvet & Hajcak, 2008). The ERN has been found to be larger in adults with obsessive-compulsive disorder (OCD)

than in controls (Endrass, Klawohn, Schuster, & Kathmann, 2008; Gehring, Himle, & Nisenson, 2000; Johannes et al., 2001; Ruchsow et al., 2005). The ERN has also been found to be larger in children with OCD (Hajcak, et al., 2008) and in undergraduates who endorse high levels of obsessive-compulsive (OC) symptoms (Hajcak & Simons, 2002). An increased ERN has also been found in people with Generalized Anxiety Disorder (GAD; Weinberg, Olvet, & Hajcak, 2010; Xiao et al., 2011) and in undergraduates who report high levels of worry symptoms (Hajcak, McDonald, & Simons, 2003) or high levels of negative affect (Hajcak, McDonald, & Simons, 2004).

These findings have led researchers to conclude that people with increased levels of anxiety have increased ERN amplitudes. However, the literature suggests that the relationship between anxiety and ERN amplitude is far from consistent. First, not all anxiety disorders show this relationship. For example, people who endorse high levels of specific phobia symptoms do not produce ERNs that are any larger than non-anxious controls (Hajcak, et al., 2003). Furthermore, there was no relationship between the ERN and phobias even when these subjects were coaxed into a highly fearful state (Moser, Hajcak, & Simons, 2005).

The fearful state that people with specific phobias experience when exposed to their feared stimulus is a high level of anxious arousal, or somatic anxiety. Anxiety researchers have conceptualized anxious arousal as being district from anxious apprehension, or worry. (Nitschke, Heller, Imig, McDonald, & Miller, 2001). Anxious arousal and anxious apprehension produce different patterns of brain activity (Nitschke, Heller, Palmieri, & Miller, 1999). The relationship between anxiety and the ERN seems to apply only to the anxious apprehension dimension of anxiety (Moser,

Moran, & Jendrusina, 2012) which would characterize OCD and GAD but not specific phobia which is associated with anxious arousal.

A second source of inconsistency in the ERN/anxious apprehension relationship involves the structure of the task used to elicit the ERN. Recent research findings suggest that the enhanced ERN in people with high levels of anxious apprehension is only found during tasks that require participants to make speeded responses to stimuli that include conflicting information about the correct response, known as response conflict tasks. However, the enhanced ERN was not found in tasks that require the trial and error learning of stimulus-response relationships. These tasks are known as Reinforcement Learning (RL) tasks (Mathews, Perez, Delucchi, & Mathalon, 2012). Specifically, enhanced ERNs have been observed in people with high levels of anxious apprehension during the Stroop (Gehring, et al., 2000; Hajcak & Simons, 2002), Flanker (Endrass, et al., 2008; Stern et al., 2010; Weinberg, et al., 2010), Go-No Go (Aarts & Pourtois, 2010; Johannes, et al., 2001), and Simon tasks (Hajcak, et al., 2008). These tasks all involve participants making a speeded response to a visually presented display that includes objects eliciting conflicting responses. In all of these tasks, participants are instructed how to respond to each kind of stimulus, so that it is clear even from the first trials when they are answering incorrectly. Figure 1 contains an example of the Flanker task, in which participants are instructed to respond to the direction of the middle arrow, while trying to ignore flanking arrows that indicate the same or the opposite direction, thus creating conflicting information about how to respond in the task that is characteristic of response conflict tasks.

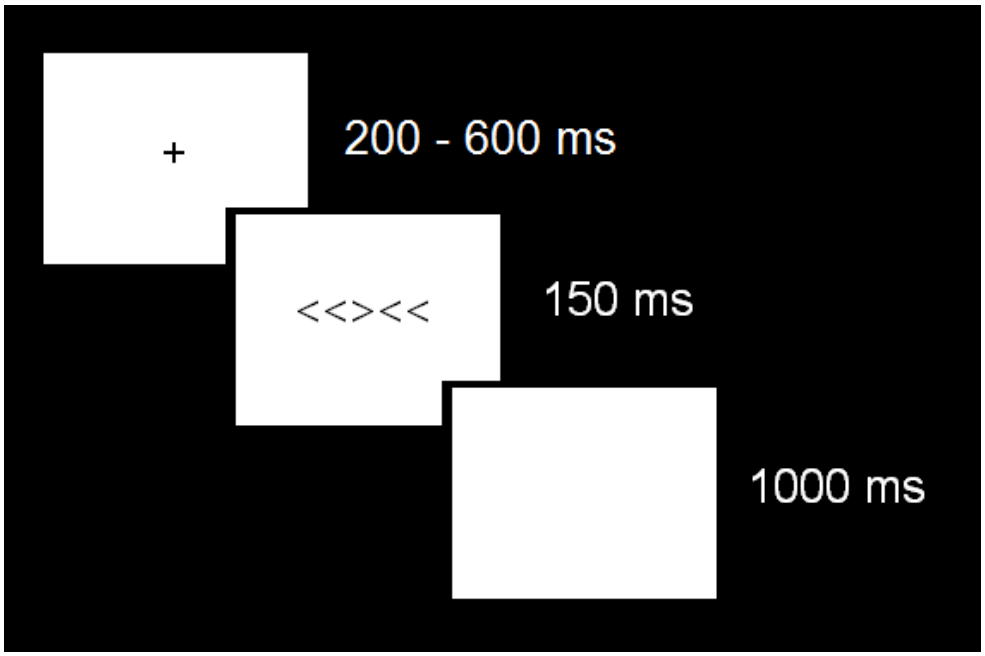


Figure 1 A Flanker task where the fixation cross is presented for 200-600 ms before the Flanker stimulus is presented for 150 ms. This is immediately followed by a blank screen during which the participant can make their response. Participants are instructed to respond quickly and accurately by indicating the direction the middle arrow is pointing.

In contrast, RL tasks involve learning stimulus-response relationships for a variety of visually presented stimuli. The "correct" response is learned only through trial and error learning based on the feedback that follows each trial. Figure 2 contains an example of an RL task. In RL tasks, people with OCD symptoms and non-anxious participants produce similar ERNs (Gründler, Cavanagh, Figueroa, Frank, & Allen, 2009; Nieuwenhuis, Nielen, Mol, Hajcak, & Veltman, 2005). Although trial by trial feedback of the kind typical of RL tasks has also been found to reduce the ERN produced by anxious people during a Flanker task (Olvet & Hajcak, 2009a), O'Toole

(2012) reported that people with OC symptoms do not produce ERNs that are larger than those produced by controls during a RL task without feedback. Therefore, it would seem that the absence of an ERN difference between anxious and non-anxious participants cannot be completely accounted for by the trial-to-trial feedback provided during RL tasks. An additional difference between the RL and Flanker tasks is that the Flanker task involves consistent stimulus-response mapping while RL tasks often have some conditions where the stimulus and response are not consistently mapped. As with trial to trial feedback, however, this feature of RL tasks does not adequately explain why anxious people are not producing enhanced ERNs during these tasks. Equivalent ERNs in OCD and control subjects have been reported even when there is a 100% consistent mapping between each stimulus and its corresponding response (Compton et al., 2010; O'Toole, Weinborn, & Fox, 2012).

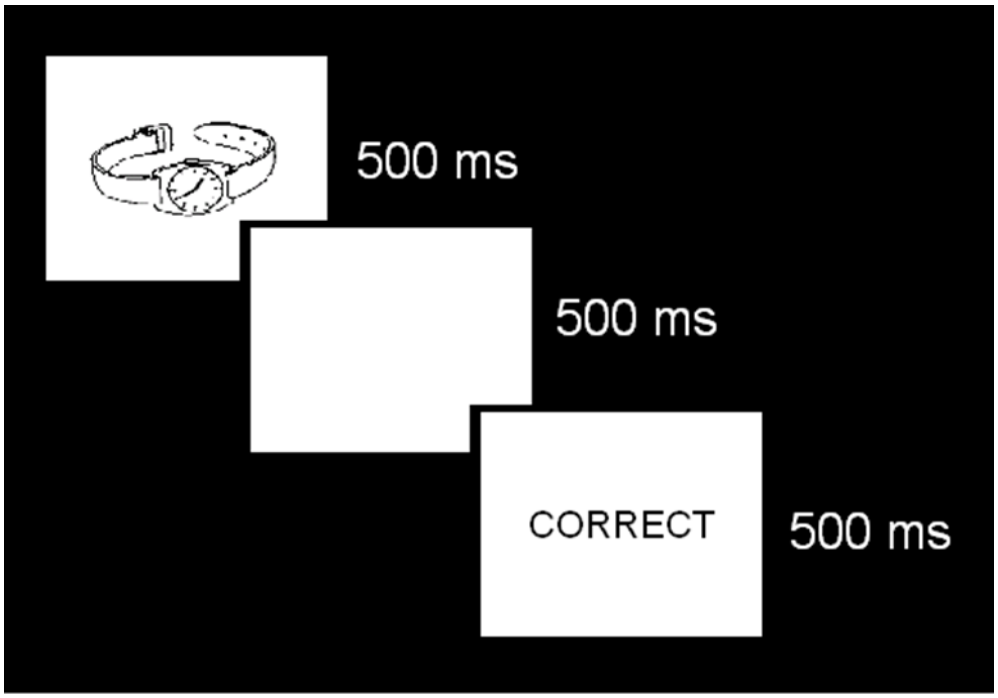


Figure 2 A Reinforcement Learning task where the stimulus picture is presented for 500 ms. This is immediately followed by a blank screen during which the participant can make their response. After the participant respond they are provided with feedback about whether they had responded correctly or incorrectly. Participants are instructed to learn the stimulus-response mapping through trial and error.

The lack of an anxious apprehension effect on the ERN during RL tasks would suggest that either some unknown aspect of these learning tasks neutralizes or counteracts OCD patients' high levels of response monitoring or there is some distinct aspect of the response conflict tasks that creates a larger ERN. Between these two competing hypotheses, the first seems more parsimonious given the nature of anxious apprehension. Since people with OCD report higher levels of concern over mistakes (Lee et al., 2009) and worry is associated with perfectionism (Fergus & Wu, 2011), it seems more likely that anxious apprehension is associated with increased error

sensitivity and people with anxious apprehension are more physiologically sensitive to making mistakes. If so, then there is something about RL tasks that blunts this natural sensitivity.

It is possible that people with high levels of anxious apprehension are not sure if they are answering incorrectly in the RL tasks. It is known that people with OCD have a meta-memory and meta-attention deficits; they tend to distrust their memories and have less confidence that they are paying adequate attention (Hermans, Martens, De Cort, Pieters, & Eelen, 2003). Although this meta-cognitive deficit was originally characterized as being related to checking behavior, a recent review (Cuttler & Graf, 2009) points out that the retrospective meta-memory deficit found in people with OCD is not specific to checkers.

There has been much less research on meta- memory and meta-attention deficits in GAD and people with high levels of worry. However, there is some evidence that GAD symptoms are associated with interpersonal checking (Coleman, Pieterefesa, Holaway, Coles, & Heimberg, 2011), so it is possible that worriers and people with OC symptoms have similar meta-memory and meta-attention deficits.

Unlike in response conflict tasks such as the Flanker and Stroop tasks, the RL task does not include instructions that tell participants how to respond to each stimulus (i.e., the stimulus/response mapping). This raises the possibility that someone with a meta-memory or meta-attention deficit, such as participants with high levels of anxious apprehension, might not trust their memory of the association between stimuli and their associated responses. It is possible that people with anxious apprehension are especially uncertain about the accuracy of their responses during an RL task. Uncertainty has been shown to attenuate the ERN and decrease the difference between

the ERN and Correct Related Negativity (CRN) in healthy young participants (Pailing & Segalowitz, 2004). If people with high levels of anxious apprehension were uncertain about their response accuracy during RL tasks, it might explain their lack of an enhanced ERN.

The current series of experiments tests the hypothesis that people with high levels of anxious apprehension are uncertain about the accuracy of their responses during RL tasks, and that their uncertainty attenuates the amplitude of their ERN in these tasks. Experiment 1 was conducted to address various aspects of this hypothesis. First, individuals with high levels of worry were compared to individuals with high levels of OC symptoms to determine whether both would produce smaller ERNs during the RL task or whether that might be a unique associate of OCD. It was important to explore this question because the enhanced ERN has been found in both worriers and people with OC symptoms but both groups have not been assessed using RL tasks. The second aspect of the main hypothesis addressed was whether people with high levels of worry symptoms have meta-memory and meta-attention deficits that are similar to those observed in people with high levels of OC symptoms. The meta-memory research literature has focused primarily on people with OC symptoms, so it has yet to be established whether people with high levels of worry also have meta-memory deficits. A third issue addressed in Experiment 1 was whether people with OC and worry symptoms report higher levels of uncertainty about their responses in a RL task than they do in a Flanker task and whether the higher uncertainty might actually correspond to less accuracy in identifying when they had made a correct response. The final question that Experiment 1 aimed to address was whether a person's decreased level of meta-memory or meta-attention are related to their

reported uncertainty and ERN amplitude during the RL task. Experiment 2 asked whether uncertainty about accuracy could be induced in non-anxious people during a RL task, and whether this would result in a decreased ERN amplitude. Experiment 3 aimed to decrease the uncertainty of anxious people in a RL task, and evaluate its effect on ERN amplitude.

Chapter 2

EXPERIMENT 1

Previous studies have shown that people with OC symptoms produce larger ERNs compared to the ERNs produced by non-anxious people in the Flanker but not the RL tasks. Other studies have shown that worriers also produce larger ERNs compared to the ERNs produced by non-anxious people during the Flanker task. The ERNs of worriers have not yet been measured during the RL task, however. Therefore the first question addressed in Experiment 1 was whether this phenomenon seen in OCD patients extended to worriers. Would people who reported high levels of worry symptoms produce a decreased ERN during the RL task compared with the ERN they produced during the Flanker task?

Past studies have shown that people with OCD have lower levels of meta-memory. It was hypothesized that those deficits might contribute to the difference in ERN between the Flanker and RL tasks for people with OC symptoms. The second question that was explored in Experiment 1 was whether people with OC and worry symptoms report higher levels of meta- memory deficits than non-anxious people, and whether those deficits would correspond to smaller ERNs in those groups.

It was hypothesized that anxious people would not only report higher levels of meta-memory deficits, but also report feeling more uncertain about their performance during the RL task. The third question to be addressed in Experiment 1 was whether anxious people report feeling more uncertain about the accuracy of their responses during the RL task compared with their reported uncertainty during the Flanker task.

Experiment 1 also allowed us to examine the hypothesized mediational relationship between worry and OC symptoms, reported uncertainty during the tasks, meta-memory and meta-attention deficits, and ERN amplitude during the two tasks. It was hypothesized that the reduction in ERN amplitude in the anxious groups between the Flanker and the RL task would be mediated by the participant's level of uncertainty in the RL task. It was also predicted that a participant's level of uncertainty during the RL task would be mediated by the participant's meta-attention and meta-memory deficits.

Method

Participants

Eighty-seven female undergraduates participated in the experiment. Moran, Taylor, and Moser (2012) reported that the increased ERN in anxious participants was present only in the female participants of their sample. Therefore, in the current experiment only female participants were included in order to maintain the homogeneity of the sample. Pre-screening questionnaires were administered to the PSYC 100 subject pool in order to identify participants with either a high level of OC symptoms, a high level of worry symptoms, or low levels of both OC and worry symptoms. Students completed the OCI-R and PSWQ during online pretesting. Thirty female students who scored above 20 on the OCI-R and below 57 on the PSWQ constituted the high OC group. Thirty female students who scored above 63 on the PSWQ and below 13 on the OCI-R made up the high worry group. Twenty-seven female students who scored below 12 on the OCI-R and below 55 on the PSWQ were selected for the non-anxious group. Additionally, participants were pre-screened for

depression. Because studies of the ERN that have included participants with comorbid anxiety and depression have shown that this comorbidity is associated with a reduced ERN amplitude (Weinberg, Klein, & Hajcak, 2012), subjects scoring over 18 on the BDI-II were excluded from the experiment. Participants received course credit for their participation. Data from twenty-three participants were excluded from analyses, three due to reporting a current major depressive episode, one due to experimenter error, and eight because they responded to less than 60% of the trials correctly in one or more of the tasks. Based on analyses done by Olvet and Hajcak (2009b) indicating that the amplitude of the ERN is reliable with a minimum of six error trials, eleven participants were excluded because they had less than six usable error trials in one or more of the tasks. Group means on the self-report measures are reported in Table 1.

Table 1 Group Means on Self-Report Measures for Experiment 1

Group (n)	PreOCI-R	PrePSWQ	PreBDI-II	OCI-R	PSWQ	BDI-II	Cog Conf
OC (22)	32.5	47.5	7.6	22.5	48.1	7.6	19.4
Worry (21)	6.6	70.6	7	9.4	57.7	6.9	13.9
NonAnx (21)	6.1	43.3	5.2	8.1	39.1	3.3	12.5

Note. Pre = Measured at Pre-Test.

Measures

See Appendix for all self-report measures.

OCI-R

The Obsessive-Compulsive Inventory – Revised (OCI-R; Foa et al., 2002) is an 18-question self-report measure for assessing symptoms of OCD. The OCI-R includes six subscales: washing, checking, ordering, obsessing, hoarding, and neutralizing.

PSWQ

The Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) is a 16-question self-report measure for assessing worry and GAD symptoms. The PSWQ has been found to significantly discriminate college samples (a) who met all, some, or none of the diagnostic criteria for GAD.

BDI-II

The Beck Depression Inventory-II (BDI-II: Beck, Steer, & Brown, 1996) is a 21- item self-report measure that assesses depressive symptomology that includes items from the DSM diagnostic criteria for a major depressive episode. The question asking participants about suicidal ideation and intent was removed from the BDI-II.

MINI

The Mini International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) is a structured clinical interview that assess for the DSM-IV (American Psychiatric Association, 2000) criteria for variety of anxiety, mood, and eating disorders. The MINI was designed to be a short but accurate structured psychiatric interview. The sections on psychotic disorders, suicidality, and substance use disorders were not included in the interview. Additionally, the question on suicidal thoughts was

not included in the Major Depressive Episode section. The MINI was administered by a clinical psychology graduate student.

MCQ

The Meta-Cognitions Questionnaire (MCQ; Cartwright-Hatton & Wells, 1997) is a 65-item self-report questionnaire designed to measure beliefs about worry and intrusive thoughts. It contains five sub-scales: Positive Beliefs About Worry; Negative Beliefs About the Controllability of Thoughts and Corresponding Danger; Cognitive Confidence; Negative Beliefs about Thoughts in General, including Themes of Superstition, Punishment and Responsibility, and Cognitive Self-Consciousness. For the current experiment, only the Cognitive Confidence scale which is composed of 10 items was administered. The Cognitive Confidence scale measures confidence in one's memory and attention.

Tasks

Flanker task

A modified Erikson Flanker task (Eriksen & Eriksen, 1974) was used. In the Flanker task, congruent (< < < < <; > > > > >) and incongruent (< < > < <; > > < > >) stimuli were presented for 150 ms. Participants were instructed to respond by pressing a button corresponding to the direction of the center arrow. Participants were encouraged to respond quickly and accurately. Participants completed 15 blocks of 40 trials for a total of 600 trials. After one out of twenty correct trials the participants were prompted to indicate whether they thought their previous response was correct, and how certain they were about their accuracy on a scale from 1 to 5. The participants were also prompted to rate their certainty after half of the error trials.

RL task

A task modeled on the 100% mapping learning task in O'Toole et al. (2012) was used. The imperative stimuli were black and white drawings published by Snodgrass and Vanderwart (1980). There were two blocks with 350 trials each. The first 100 trials of each block were learning trials were feedback was presented, and the latter 250 trials were test trials that did not include feedback. On each trial, the imperative stimulus was presented for 700 ms. On the learning trials a blank screen was presented for 500 ms, and then the feedback was presented for 500 ms. The feedback stimuli were the words "CORRECT" and "INCORRECT" presented on the center of the screen during the learning block. On the test trials, the blank screen was presented for 1000 ms and no feedback was displayed. Participants were required to respond within 700 ms on each trial. If participants did not make a response within this time frame then the feedback stimuli was the phrase "TOO SLOW". A unique set of six imperative stimuli was used for each block. Participants were not instructed how to respond. They were instructed to learn the correct response through trial and error. The participant was prompted to answer the same certainty questions used in the Flanker task on one out of 25 of the test trials. The participant was also asked to respond to the certainty questions on half of the error trials that occurred during the test block.

Procedure

Participants were fitted with an electrode cap and given instructions for the two tasks. The order of the two tasks was counterbalanced across participants. Participants completed the tasks while seated alone at a computer in a room as EEG was recorded. At the conclusion of the two tasks, participants completed the OCI-R, PSWQ, BDI-II,

and the Cognitive Confidence scale from the MCQ in an online questionnaire. Then a clinical psychology graduate student completed the MINI with the participant in a private room in order to determine if the participant met DSM-IV criteria for GAD, OCD, or any other Axis I disorder.

Electrophysiological recording and processing

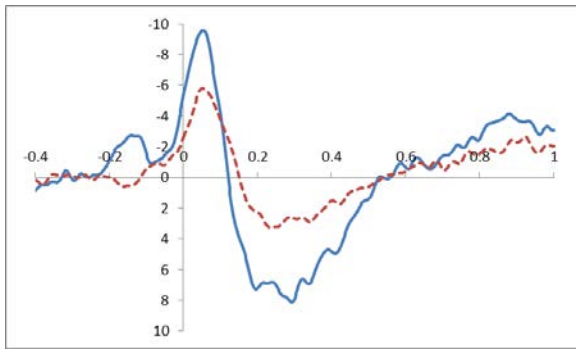
EEG was recorded from 32 Ag/Cl sintered electrodes embedded in an electrode cap. EEG was digitized at 512 Hz using ANT acquisition hardware (Advanced Neuro Technology, Enschede, The Netherlands) with an average electrode reference and forehead ground. The EEG was re-referenced offline to the average of the two mastoid sites. Continuous EEG was corrected for eye blinks with ASA software from ANT. A 0.1-30 Hz bandpass filter was used. Artifacts that exceeded a threshold of -75 μV or +75 μV during the trial or the baseline period were rejected. Response-locked ERP averages were created and baseline corrected using a baseline period of -400 ms to -200 ms. The dERN was measured as the mean amplitude during the first 100 ms after correct trials subtracted from the mean amplitude of error trials during that same time window. dERNs were only extracted from trials during the test blocks in the RL task. The components were averaged across a region of interest that included Fz, Cz, FC1, and FC2.

Results

The first question that was addressed in Experiment 1 was whether findings from previous studies that have shown that OC symptoms are associated with larger dERNs in the Flanker task but not in the RL task would be replicated in the present sample. Experiment 1 further examined whether people with high levels of worry

would similarly produce a decreased dERN during the RL task compared with the dERN they produce during the Flanker task. These questions were examined with a series of paired-samples t-tests that compared dERNs in each task for each of the groups. Participants in the OC group had a larger dERN amplitude during the Flanker task than during the RL task, t (21) = 2.496, p = .021. No significant difference in the dERN between the tasks was found for the Worry group, t (20) = .138, p = .892, or for the Non- Anxious group, t (20) = -.14, p = .890. Figure 3 shows the dERNs for both tasks in each group. When the groups are examined separately, it can be seen that people who endorse OC symptoms did, as predicted, have larger dERNs during the Flanker task than during the RL task, but this was not true for the worriers. The second question that was examined in Experiment 1 was whether people with OC and worry symptoms report higher levels of meta-memory deficits than non-anxious people. To examine this question, a one-way ANOVA was calculated on participants' cognitive confidence as measured with that subscale of the MCQ. There was a significant difference between anxiety groups on cognitive confidence, F (2, 61) = 15.207, p < .001. Post-hoc tests using the Bonferroni correction for multiple comparisons revealed the high OC group reported significantly higher levels of meta-memory and meta-attention deficits than either the worry group or the non-anxious group, and those other groups were not significantly different from each other (see Figure 4). The results revealed that the meta-memory deficit was specific to people with OC symptoms and it was not a more general anxiety correlate.

a)



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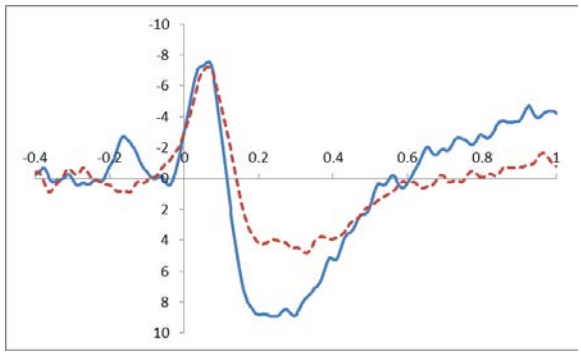

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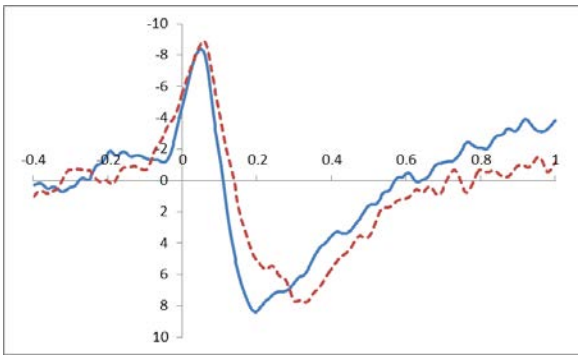

Figure 3 Response-locked ERP difference waves for the a) High OC, and b) High Worry, and c) Non-Anxious groups. The solid blue line is the grand average for the Flanker task, the dashed red line is the grand average for the RL task.

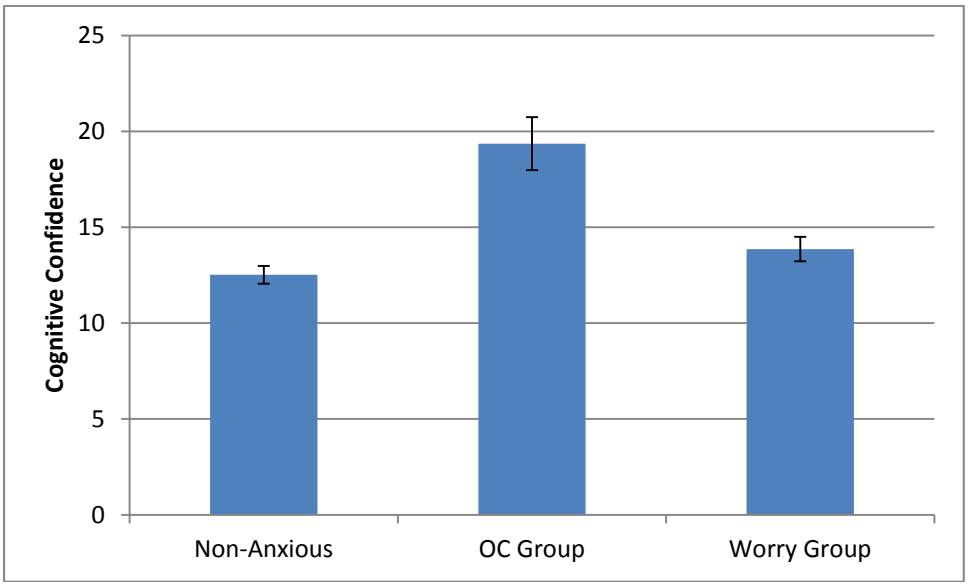

Figure 4 Cognitive confidence as measured with that sub-scale of The Meta-Cognitions Questionnaire for each group in Experiment 1.

The third question that was addressed in Experiment 1 was whether anxious people report feeling more uncertain about the accuracy of their responses during the RL task compared with their reported uncertainty during the Flanker task. To address this question, I calculated paired-samples t-tests comparing the reported levels of certainty on each task for each group. No significant difference in certainty between the tasks was found for the Worry group, t (20) = -1.48, p = .155, or for the Non-Anxious group, t (20) = -1.147, p = .265. Participants in the OC group reported significantly higher levels of certainty during the Flanker task than during the RL task, t (21) = -2.667, p = .014. Figure 5 shows mean levels of certainty for each group in both of the tasks.

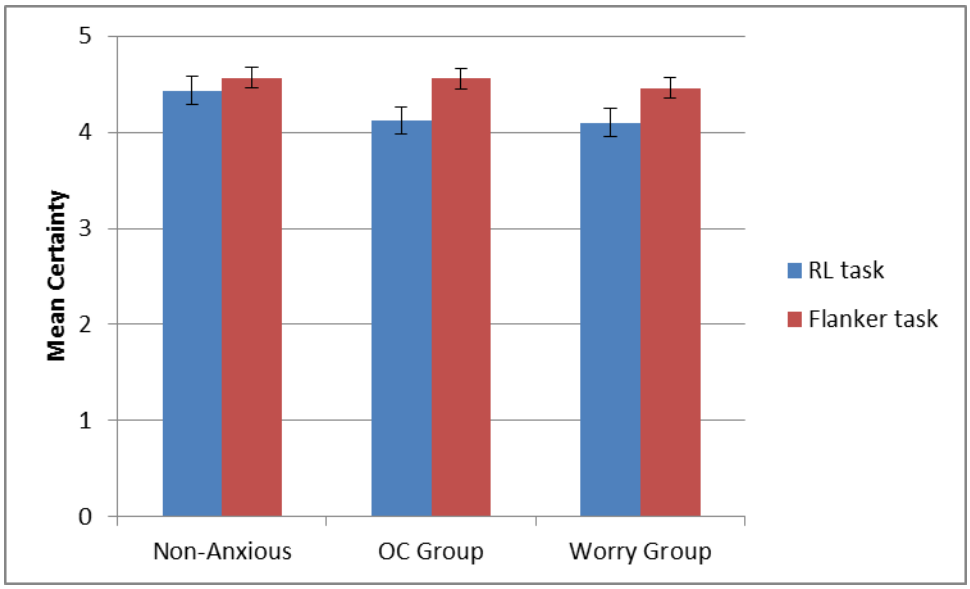

Figure 5 Self-reported uncertainty during the RL and Flanker tasks during Experiment 1.

In addition to analyzing participants' responses to the question of their uncertainty, the accuracy of participants reports of whether they had responded correctly to the previous trial were calculated. Paired samples t-tests for each group's hit rate (the proportion of correct trials that were identified as such), false alarm rate (the proportion of incorrect trials that were identified as being correct), and the total proportion correct (the proportion of hits and correct rejections out of all responses) were also calculated. For the OC group, hit rates were higher during the Flanker task than during the RL task, t (20) = 3.516, p = .002. This effect was not present in the worry group, t (20) = .633, p = .534, or the non-anxious group, t (20) = 1.435, p = .167. False alarm rates were higher during the RL task than during the Flanker task in all groups though this effect reached significance only in the non-anxious, t (20) = -3.685, p = .001 and worry group, t (20) = -3.06, p = .006. The effect was marginally

significant in the OC group, t (20) = -2.04, p = .055. Participants in all groups were more accurate when identifying correct and erroneous trials during the Flanker task than during the RL task, t (20) = 4.617, p < .001 for the non-anxious group, t (20) = 3.866, p = .001 for the OC group, and t (20) = 3.638, p = .002 for the worry group. Table 2 shows the means of each of these measures for each group during the two tasks. All participants had higher false alarm rates and lower overall accuracy in identifying the accuracy of their responses during the RL task compared with the Flanker task. People who reported high levels of OC symptoms were worse at identifying when they correctly responded during the RL task than during the Flanker task, and showed worse sensitivity for detecting correct responses during the RL task as well.

Table 2 Accuracy of Participants' Identification of Correct and Error Trials during Experiment 1

Measure	Flanker task	RL task	*t* Score	*p* value
Non-Anxious				
Hit Rate	.945	.891	1.435	.167
False Alarm Rate	.077	.23	-3.685	.001
Correct	.938	.813	4.617	< .001
Obsessive Compulsive				
Hit Rate	.943	.806	3.516	.002
False Alarm Rate	.178	.307	-2.04	.055
Correct	.87	.729	3.866	.001
Worry				
Hit Rate	.888	.868	.633	.534
False Alarm Rate	.122	.289	-3.06	.006
Correct	.891	.75	3.638	.002

Note. Correct = Total Proportion Correct.

Finally, two mediational paths were hypothesized. Specifically, the reduction in dERN amplitude in the anxious groups between the Flanker and the RL task was predicted to be mediated by the participant's level of uncertainty in the RL task such that a participant's level of anxiety would be positively related to their level of uncertainty during the RL task, and that level of uncertainty would predict the

difference between that participant's dERN during the Flanker task and the RL task. To explore this hypothesized mediational path using the Baron and Kenny (1986) method. First the difference between the participants' dERN amplitudes from the two tasks was regressed on their pre-testing OCI-R scores. OCI-R scores were a marginally significant predictor of the difference in the dERN amplitudes between the two tasks, R2 = .051, F (1, 62) = 3.358, p = .072. Specifically, higher scores on the OCI-R predicted a larger dERN on the Flanker task compared with the RL task. However, when participants' reported uncertainty during the RL task was included in the regression, the original relationship was not mediated by task uncertainty. The results of the multiple regression indicated the OCI-R scores and reported uncertainty during the RL task together explained a marginally significant amount of the variance, R2 =.080, F (2, 61) = 2.653, p = .079. OCI-R scores were a marginally significant predictor of the difference in dERN amplitudes between the tasks, β = -.218, p = .081, but uncertainty reported during the RL task was not a significant predictor of the difference in dERN amplitudes between the tasks, β =.169, p = .173.

It was also predicted that the relationship between a participant's level of anxiety and reported uncertainty during the RL task would be mediated by the participant's meta-attention and meta-memory deficits such that a participant's level of anxiety would be positively associated with their level of meta-memory deficits which in turn, would be associated with the participant's level of uncertainty during the RL task. To explore this hypothesized mediational path using the Baron and Kenny (1986) method, the participant's self-reported uncertainty during the task was regressed on their pre-testing OCI-R scores. OCI-R scores were not a significant predictor of the reported uncertainty during the RL task, β = -.051, t (62) = -.405, p =

.687.When participants' cognitive confidence was added as a predictor, neither OCI-R scores, β = -.079, t (61) = -.51, p = .612, or cognitive confidence, β =.049, t (61) =.317, p = .753 were significant predictors of self-reported uncertainty during the RL task. Therefore, cognitive confidence did not mediate the relationship between OC symptoms and uncertainty during the RL task.

To explore any differences between the groups on reaction time or accuracy during the tasks a 3 (group) X 2 (task) ANOVA was calculated on various behavioral performance measures. Participants responded more accurately during the Flanker task than during the RL task, F (1, 60) = 18.452, p < .001. There was not a significant effect of group on accuracy, but there was a marginally significant group by accuracy interaction, F (2, 60) = 2.713, p = .074. While all of the participants performed worse on the RL task, the high OC group's performance on that task was especially poor (see Figure 6). There was also a significant effect of task on reaction time, F (1, 60) = 348.973, p < .001; reaction time on correct trials, F (1, 60) = 353.386, p < .001; reaction time on error trials, F (1, 60) = 463.829, p < .001; and reaction time on trials that follow error trials, F (1, 60) = 24.296, p < .001. All of these results reflect the fact that participants responded more quickly to those trials during the Flanker task than during the RL task. Additionally, participants were significantly less accurate on post-error trials during the RL task than during the Flanker task, F (1, 60) = 51.295, p < .001. There were no significant group differences on any of these behavioral performance measures, and none of the other task by groups interactions were significant (see Table 3).

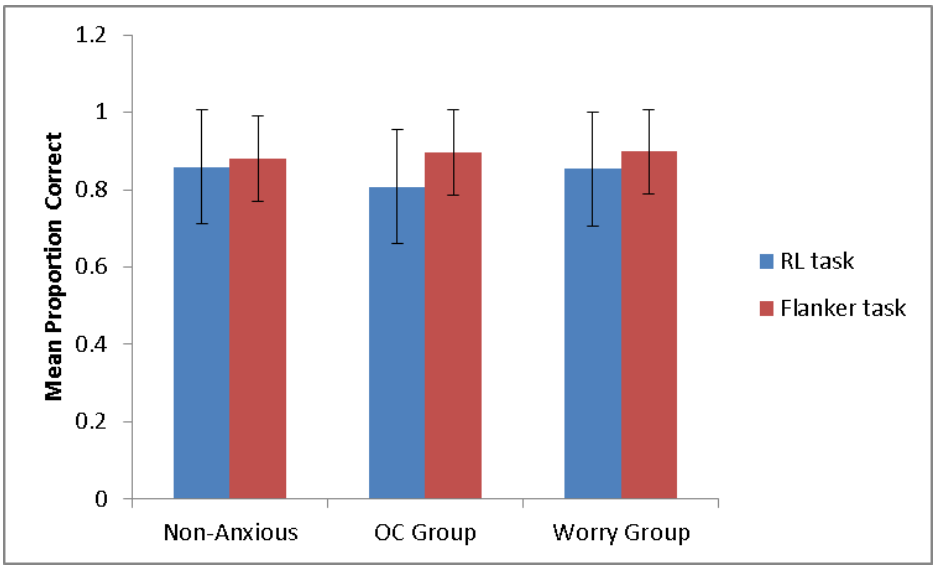

Figure 6 Mean proportion correct for both tasks in all groups in Experiment 1.

Table 3 Behavioral Results and ANOVA Examining Task by Group Interactions for Experiment 1

Measure	Flanker task	RL task	*t* Score	*p* value
Non-Anxious				
Hit Rate	.945	.891	1.435	.167
False Alarm Rate	.077	.23	-3.685	.001
Correct	.938	.813	4.617	< .001
Obsessive Compulsive				
Hit Rate	.943	.806	3.516	.002
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Worry				
Hit Rate	.888	.868	.633	.534
False Alarm Rate	.122	.289	-3.06	.006
Correct	.891	.75	3.638	.002

Note. Correct = Total Proportion Correct.

Discussion

The first question that Experiment 1 addressed was whether the decreased dERN in the RL task that has been found in previous studies with participants who report OC symptoms would also be found for people who report high levels of worry.

When the groups were analyzed separately, people with OC symptoms produced larger dERNs during the Flanker task than during the RL task, but this was not true for the worriers or non-anxious participants. People with OC symptoms respond to certain tasks, such as the RL task, in a way that was different than the way participants with only a high level of general anxious apprehension, but no OC symptoms respond to the tasks. The presence of OC symptoms or some other feature that was unique to the OC group that is above and beyond level of anxious apprehension seem to be what is related to the different reaction to the tasks.

Participants with OC symptoms also reported higher levels of meta-memory deficits and they had higher hit rates in identifying when they had responded correctly during the Flanker task than during the RL task. All together, these differences in the way that people with OC symptoms respond to the RL task suggest that people with OC symptoms were indeed less certain about their performance during the RL task. They have lower levels of cognitive confidence, and are less accurate at identifying when they responded correctly during the RL task. Since the participant's level of uncertainty during the tasks seems to have been the key difference between the way people with OC symptoms experienced the two tasks, uncertainty was further explored in Experiments 2 and 3.

Past studies have shown that people with OC symptoms report a deficit in meta-memory and meta-attention. That deficit might contribute to the difference in dERN between the RL and Flanker tasks in people with OC symptoms. In the present experiment, cognitive confidence was measured and the results revealed a deficit in cognitive confidence in people who report OC symptoms, but not in those who report more general worry symptoms. It follows that the OC participants' lower level of

cognitive confidence lead to them to feel more uncertain about their performance during the RL task where the correct responses must be remembered since there was no attribute of the stimuli that would suggest how that participant should have responded. Consistent with this idea, the OC group reported feeling less uncertain about their responses during the Flanker task than during the RL task, but there was no such difference in uncertainty during the two tasks for the worriers or non-anxious participants. As a compliment to the uncertainty measure, OC people were actually worse at identifying when they correctly responded during the RL task than during the Flanker task.

Higher scores on the OCI-R predicted a larger dERN difference on the Flanker task compared with the RL task. When participants' reported certainty during the RL task was added as a predictor in the regression, however, the original relationship was not mediated by task uncertainty. Additionally, OCI-R scores were not a significant predictor of the reported uncertainty during the RL task. This failure to find mediators of the relationship could be due to insufficient power or it could be due to a true lack of a relationship between these variables. Experiment 1 provides modest support for the hypothesis that the participants with OC symptoms are feeling more uncertain about the accuracy of their responses during learning tasks which results in smaller ERNs. Further, this effect is specific to people with OC symptoms and does not generalize to people with anxiety more broadly.

Chapter 3

EXPERIMENT 2

Experiment 1 revealed that meta-memory deficit occurred exclusively for the high OC group and that the OC group was also more uncertain about their responses on the RL task. Additionally the high OC group produced smaller dERNs during the RL task. Taken together, this pattern of results suggests that people with OC symptoms are more uncertain about their performance during the RL task, and that uncertainty decreases the salience of errors which results in a smaller dERN in the RL task compared with the Flanker task. To further explore how uncertainty affects the processing of errors during the RL task, Experiment 2 aimed to make non-anxious people feel more uncertain during the RL task, and to examine the effect of this increased uncertainty on their dERNs.

Several studies have found that having non-anxious participants repeatedly check something produces a decrease in confidence of the memory for what is being checked (Alcolado & Radomsky, 2011; Radomsky, Gilchrist, & Dussault, 2006). Radomsky and Alcolado (2010) found that this effect holds for things that are either mentally or physically checked. Given these findings, it was expected that participants who performed a RL task would become more uncertain about the accuracy of their response if they are frequently asked to report how uncertain they were about their previous response.

Experiment 2 was designed to test two hypotheses. These were: 1) that non-anxious participants who are asked to report on their level of uncertainty about their

response during a RL task would become more uncertain about their responses and would produce smaller ERNs

Method

Participants

Fifty-nine female undergraduates participated in the experiment. Pre-screening questionnaires were administered to the PSYC 100 subject pool in order to identify participants with low levels of OC and worry symptoms. As in Experiment 1, students completed the OCI-R, PSWQ, and BDI-II during online pretesting. Students who scored less than 13 on the OCI-R, less than 55 on the PSWQ and less than 19 on the BDI-II were selected for the experiment. Participants received course credit for their participation. Data from four participants were excluded from analyses, one due to equipment malfunction, two because they had less than six usable error trials, and one because she responded to less than 60% of the trials correctly during the task. Group means on the self-report measures are reported in Table 4.

Table 4 Group Means on Self-Report Measures for Experiment 2

Group (n)	PreOCI-R	PrePSWQ	PreBDI-II	OCI-R	PSWQ	BDI-II
Regular RL (27)	6.6	43	5.9	7.1	38.1	5.2
Checking RL (28)	5.9	41	4.3	7.4	35.6	4

Note. Pre = Measured at Pre-Test

Tasks

The Regular RL task was the same as the RL task used in the first experiment. The Checking RL task was identical to the Regular RL task except for the post-trial queries during the test blocks. -. After each trial, participants were asked to indicate whether their previous response was correct and how certain they felt about their response by rating their level of uncertainty on a scale from 1 to 5.

Procedure

Participants were randomly assigned to the regular task condition or the checking task condition after they consented to participate. They were fitted with an electrode cap and given instructions for the task. Participants completed the task while seated alone at a computer in a room as EEG was recorded. At the conclusion of the task, participants completed the OCI-R, PSWQ, and BDI-II measures in an online questionnaire to confirm that they had not become more anxious since completing the pre-screening questionnaire. The same measures, psychophysiological recording and processing that were used in Experiment 1 were used in this experiment.

Results

Experiment 2 aimed to explore whether uncertainty could be decreased in non-anxious people during the RL task, and whether the participants' level of uncertainty would affect the amplitude of the dERNs produced during the task. To address the first question, the checking task was designed to decrease participants' level of uncertainty during the task. It was hypothesized that non-anxious participants who were asked to report on their level of uncertainty about their response during a RL

task would become more uncertain about their responses during the course of the task. The following HLM level-1 equation was used to test this prediction:

$Uncertainty_{ti} = \beta_{00} + \beta_{10} (Time_{ti}) + e_{ti}$

In this model, the β_{00} represents the intercept, which was the level of uncertainty, for trials *t* nested within individuals *i*, across all participants. Time is a variable where 1 represents the average of the first 50 trials, 2 represents the average of the next 50 trials, and so on. β_{10} represents the slope coefficient for Time and e_{ti} is the error term. Therefore, it had been hypothesized that β_{10} would be negative, indicating a decrease in certainty over time. Parameter estimates and significance tests for this HLM model are presented in Table 5. The Time slope was significant and it was positive which indicates that participants actually became more certain about the accuracy of their responses over the course of the task (see Figure 7). HLM Fixed

Table 5 HLM Fixed Effects Regressing Time on the Participant's Reported Uncertainty

Fixed effects (intercept, slopes)	Estimate (SE)	t (27)	p-value
Intercept, β_{00}	4.458 (.073)	60.758	< .001
Time, β_{10}	.045 (.005)	8.625	< .001

Note. HLM = Hierarchical Linear Modeling.

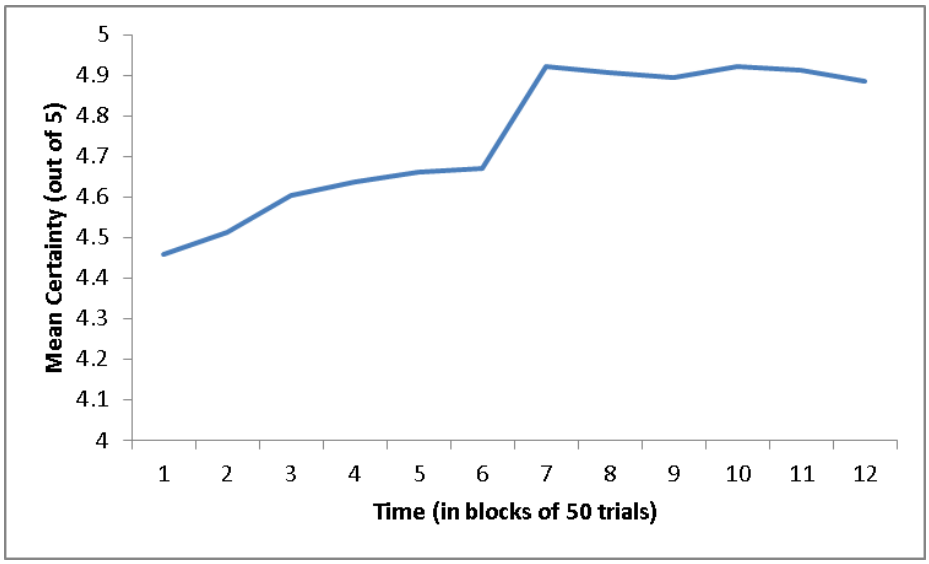


Figure 7 Self-reported uncertainty over the course of the Checking RL task in Experiment 2.

Participants' accuracy in identifying correct and erroneous responses during the checking condition was examined over the course of the experiment as another way to examine whether the participants' level of task uncertainty changed during the task. Hit rate, false alarm rate, and total proportion correct were calculated for each quarter of responses. These were analyzed with a repeated measures ANOVA. There was a linear effect of time on the participants' hit rate, F (1, 27) = 4.605, p = .041. Participants in the checking condition improved in their ability to identify correct trials as the task went on. This finding reinforces the participants' self-report that they felt less uncertain about their accuracy as the task went on. There were not any significant effects of time on participants' false alarm rate, or total proportion correct.

Additionally, behavioral performance measures were analyzed in a one-way ANOVA. Participants responded more slowly to trials during the Checking RL task than during the Regular RL task, F (1, 53) = 11.002, p = .002. Participants also

responded more slowly to correct trials during the Checking RL task, F (1, 53) = 13.173, p = .001. There was no significant effect of task on accuracy or on the other behavioral performance measures (see Table 6).

Table 6 Behavioral Results and ANOVAs Examining Task Differences for Experiment 2

Measure	Regular RL task	Checking RL task	*F* Score	*p* value
Accuracy	.848	.867	.625	.433
RT	427	457	11.002	.002
CorrectRT	431	462	13.173	.001
ErrorRT	401	421	1.737	.193
PostErrRT	413	399	1.751	.191
PostErrAcc	.791	.739	1.95	.168

Note. Accuracy = Mean Proportion Correct; CorrectRT = Reaction Time in ms; CorrectRT = Reaction Time for Correct Trials; ErrorRT = Reaction Time for Error Trials; PostErrRT = Reaction Time for Trials Following an Error; PostErrAcc = Accuracy for Trials Following an Error.

The second hypothesis for Experiment 2 was that non-anxious participants would produce smaller dERNs during the Checking RL task than in the regular RL task. This hypothesis was tested with an independent samples t-test to compare dERNs between the two tasks. There was not a significant difference between the conditions in terms of the dERN, t (53) = -.166, p = .868. Therefore, the checking manipulation did not affect the amplitude of the dERN. However, since uncertainty decreased over time and almost reached zero, it might be that the dERNs from early

in the task may reflect the expected difference. The difference waves are presented in Figure 8 and show no difference between conditions in terms of the dERN.

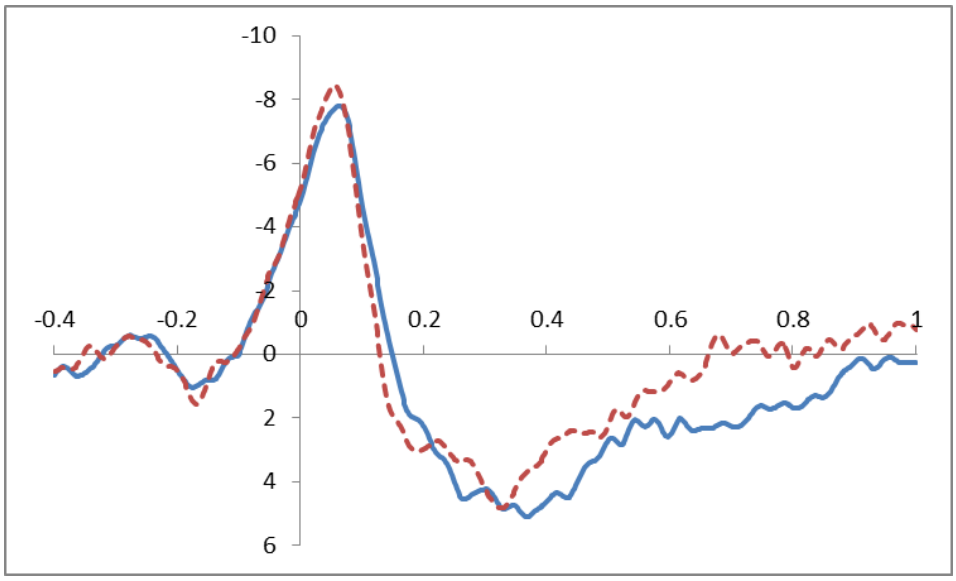


Figure 8 Response-locked ERP Difference Waves for the Checking RL (solid blue line) and Regular RL tasks (dashed red line) in Experiment 2.

Discussion

Experiment 2 examined whether uncertainty could be increased in non-anxious people during the RL task, and if so whether that would affect the participants' dERNs during the task. The checking task that was designed to increase uncertainty during the task actually ended up having the opposite effect. Self-reported uncertainty increased during the task. Since the manipulation failed and uncertainty levels were not lowered by the manipulation, it was not surprising that there was no difference in the dERNs between the two tasks.

Interestingly, there were behavioral differences in how participants responded in the two tasks. Those in the checking condition responded more slowly and were better able to identify when they responded correctly. It may be that the checking condition caused people to value accuracy over speed and slow their responses accordingly. Also, the checking may have made them pay more attention to the accuracy of their responses which improved their ability to identify correct responses. When accuracy was prioritized in a Flanker task, participants tend to respond more slowly (Gehring, Goss, Coles, Meyer, & et al., 1993). The checking manipulation may have sent the message that accuracy was more important than speed during the task which could have resulted in slower responses during the checking task. However, if that had been the case, it should also have impacted the dERN and it did not.

Chapter 4

EXPERIMENT 3

The results of Experiment 1 showed that people with OC symptoms have a smaller dERN during the RL task than during the Flanker task, and they also report feeling more uncertain about their performance during the RL task. Experiment 2 aimed to further examine this relationship between uncertainty and the dERN by increasing uncertainty in non-anxious participants. That manipulation was unsuccessful, however. Experiment 3 attempted to examine the relationship between uncertainty and the dERN by decreasing uncertainty about task accuracy in the RL task in people with OC symptoms. The first question addressed in Experiment 3 was whether task certainty can be increased in people with OC symptoms by giving them explicit instructions about how to respond on the task. The second question was whether a difference in uncertainty would be associated with a corresponding difference in the amplitude of the dERN. It was hypothesized that anxious participants who are instructed how to respond to a RL task would report less uncertainty about their responses than anxious participants in a regular RL task and that non-anxious people would report low levels of uncertainty on both tasks. A second hypothesis was that anxious participants who are instructed how to respond to a RL task would produce larger dERNs than anxious participants in a regular RL task. Non-anxious people were not hypothesized to show a difference in their dERNs between the two tasks.

Method

Participants

Fifty-seven female undergraduates participated in the experiment. Pre-screening questionnaires were administered to the PSYC 100 subject pool in order to identify a group of participants with high levels of OC symptoms and a group of participants with low levels of OC and worry symptoms. Students completed the OCI-R and PSWQ during online pretesting. Twenty-seven female students who scored above 24 on the OCI-R comprise the anxious group. Thirty female students who scored below 13 on the OCI-R and below 55 on the PSWQ were selected for non-anxious group. Additionally, as in Experiment 1, participants were pre-screened for depression and excluded from the experiment if they score over 18 on the BDI-II. Participants received course credit for their participation. Data from six participants were excluded from analyses, one due to reporting a current major depressive episode, two due to experimenter error, and three because they had less than six usable error trials on at least one of the tasks. As in Experiments 1 and 2, participants with fewer than six errors on the task were excluded. Group means on the self-report measures are reported in Table 7.

Table 7 Group Means on Self-Report Measures for Experiment 3

Group (n)	PreOCI-R	PrePSWQ	PreBDI-II	OCI-R	SWQ	BDI-II	Cog Conf
Anxious (25)	38.2	65.2	10.3	26.3	55.3	7.6	17.7
NonAnx (26)	6.3	41.4	4.9	6.6	37.1	3.5	14

Note. Pre = Measured at Pre-Test.

Tasks

The regular RL task was the same as the RL task used in in the first two experiments. The Instructed RL task was identical to the regular RL task except that participants were instructed about the stimulus-response mappings at the beginning of the experiment through a series of instruction screens that showed the pictures used during the task and identified the correct response for each picture. The Instructed RL task also included a short practice block which had untimed trials so the participants could master the stimulus-response mappings with feedback from the experimenter before starting the actual task.

Procedure

The same procedure, measures, electrophysiological recording, and processing used in Experiment 1 were used in Experiment 3.

Results

Experiment 3 aimed to decrease uncertainty in anxious people during the RL task and examine whether that decreased uncertainty would have an effect on participants' dERNs. The first hypothesis for Experiment 3 was that anxious participants would report lower levels of uncertainty during the Instructed RL task than during the Regular RL task. It was hypothesized that non-anxious participants would report low levels of uncertainty on both tasks. To test this hypothesis a 2 (group) X 2 (task) ANOVA on certainty ratings was calculated. There were no significant main effects (Group, F (1, 48) = .147, p = .703; Task, F (1, 48) = 1.537, p = .221) nor was there a group by task interaction, F (1, 48) = .396, p = .532 (see Figure 9).

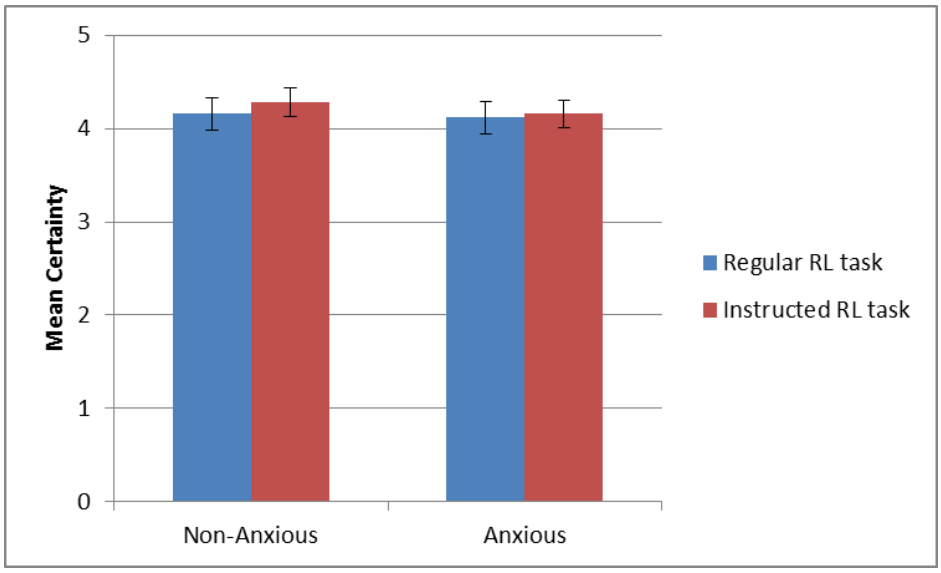


Figure 9 Self-reported uncertainty during the Instructed and Regular RL tasks for Experiment 3.

Participants' accuracy in identifying correct and erroneous responses was analyzed in terms of their hit rate, false alarm rate, and total proportion correct. Again, there were no significant effects of any of these variables. Overall, there was no difference in uncertainty between the conditions or between anxiety groups. Likewise, there was no difference in detecting accuracy for either condition or group. This suggests that the manipulation of providing participants explicit instructions on how to respond in the task was unsuccessful in altering participants' level of uncertainty during the task.

To examine the behavioral performance during the tasks, a 3 (group) X 2 (task) ANOVA on various behavioral performance measures was calculated. Participants were more accurate during the Instructed task than during the Regular task, F (1, 40) = 9.72, p = .003. There was neither a significant effect of group, F (1, 40) = .14, p = .701, nor a group by task interaction, F (1, 40) = .088, p = .769. Even though

participants did not report any differences in their level of uncertainty about the accuracy of their responses between the two tasks, they did actually respond more accurately during the Instructed task. There was not a significant effect of group or a group by task interaction on accuracy. There were no significant group differences on any of these behavioral performance measures, there were no task effects on any of the other behavioral measures and none of the task by group interactions were significant (see Table 8).

Table 8 Behavioral Results and an ANOVA Examining Task by Group Interactions for Experiment 3

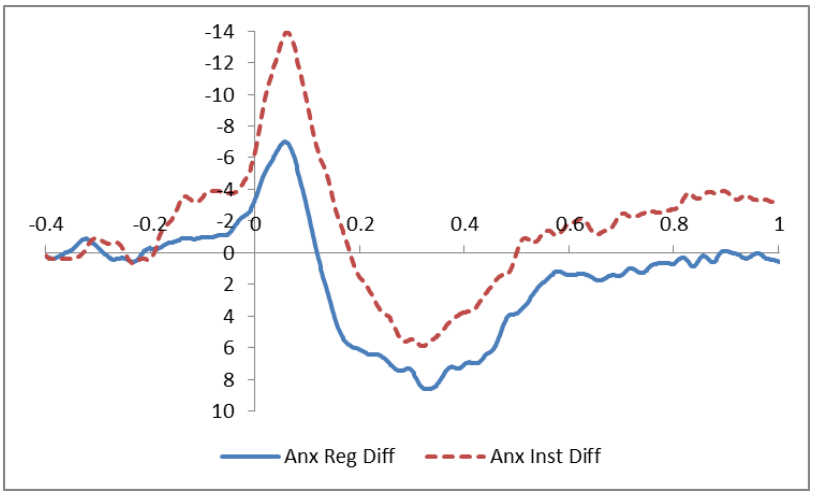
	Regular RL task		Instructed RL task			
Measure	NonAnx	Anxious	NonAnx	Anxious	*F* Score	*p* value
Accuracy	.849	.859	.883	.887	.088	.769
RT	450	447	448	448	.285	.596
CorrectRT	454	449	452	451	.220	.642
ErrorRT	426	425	415	427	1.508	.227
PostErrRT	434	429	431	441	1.053	.311
PostErrAcc	.729	.729	.751	.768	.227	.636

Note. NonAnx = Non-Anxious Group; Accuracy = Mean Proportion Correct; CorrectRT = Reaction Time in ms; CorrectRT = Reaction Time for Correct Trials; ErrorRT = Reaction Time for Error Trials; PostErrRT = Reaction Time for Trials Following an Error; PostErrAcc = Accuracy for Trials Following an Error.

The second hypothesis for Experiment 3 was that anxious participants would produce larger dERNs during the Instructed RL task than during the Regular RL task, and that the dERN in non-anxious participants would be unaffected by the instruction

manipulation because they would not feel uncertain about the accuracy of their responses in either task. A 2 (group) X 2 (task) ANOVA on dERN amplitude was calculated to examine this hypothesis. The dERN was larger during the instructed task than during the regular task, F (1, 49) = 6.056, p = .017. The main effect of group was not significant, F (1, 49) = .323, p = .572 nor was there a group by task interaction, F (1, 49) = .320, p = .574 despite the impression gleaned from the difference waves presented in Figure 10.

a)



b)

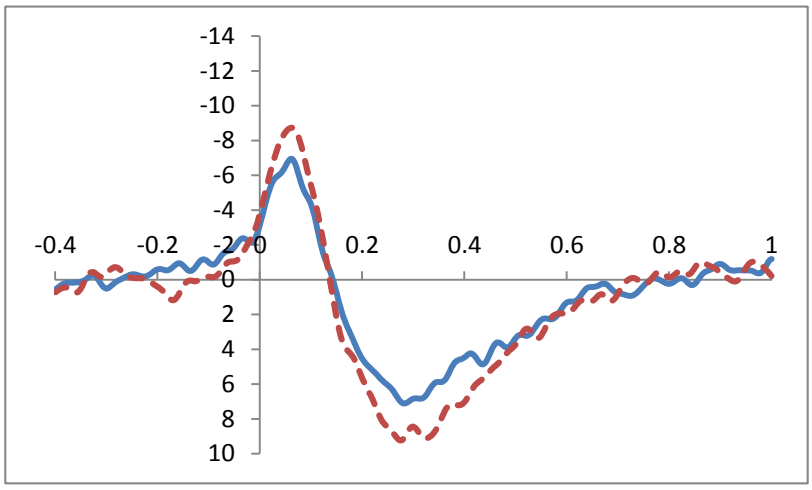


Figure 10 Response-locked ERP Difference Waves for a) the Anxious and b) Non-Anxious groups during Experiment 3. The dashed red line is the Instructed and the solid blue line is the Regular RL task.

Discussion

Experiment 3 attempted to decrease the anxious participants' level of uncertainty during the RL task, and explore what effect that decrease in uncertainty would have on their dERNs. As to the first question, there was no difference in uncertainty between the conditions or between anxiety groups. Likewise, there was no difference in detecting accuracy for either condition or group. This pattern of results might suggest that the instruction manipulation failed or at least that the measures used to assess uncertainty were not sensitive enough to pick up any change in uncertainty related to the instruction manipulation. Even though participants did not report any differences in their level of uncertainty about the accuracy of their responses between the two tasks, they did respond more accurately during the Instructed task. Despite this difference in accuracy, the self-report measure of uncertainty may not have been sensitive enough to detect a difference due to the fact that overall levels of reported uncertainty were low, and uncertainty might have been at a floor level preventing any differences from being found.

Interestingly, larger dERNs were found during the instructed task than the regular task, but that effect was not moderated by the participant's level of anxiety. Both anxious and non- anxious participants produced larger dERNs during the instructed task than during the regular task. This finding is consistent with the idea that when participants are clear about how they are supposed to respond, there was a more serious violation of expectation, and thus a larger dERN when a mistake was made.

Additionally, participants were more accurate during the instructed task than during the regular task. This finding supports the idea that the instruction manipulation was successful in helping the participants to respond more accurately during the instructed task, however it was unclear whether there was a corresponding increase in

the participant's feeling of uncertainty about their responses. Since participants were more accurate during the instructed task, their increased dERNs in that task could be due to the fact that they were making fewer errors. ERNs tend to be larger during conditions that emphasize accuracy.

Chapter 5

GENERAL DISCUSSION

Numerous studies have shown that anxious people produce larger ERNs than non- anxious people when making mistakes in response-conflict tasks such as the Stroop, Simon, or Flanker task. However, this enhancement was not observed in several recent studies in people with OC symptoms when their mistakes were made during tasks that require learning stimulus- response relationships. It was unclear why the normally enhanced ERN was absent in these reinforcement learning tasks.

Previous studies have shown that like people with OC symptoms, worriers also produce large ERNs during response-conflict tasks. However, the ERNs of worriers had not been measured during learning tasks before the present experiment, so it was unclear whether this decreased ERN for learning tasks compared to response conflict tasks that had been seen in OCD patients would extend to worriers. Experiment 1 examined whether this effect was specific to people with OC symptoms, or whether it applied to anxious people more broadly.

In Experiment 1, participants with OC symptoms produced larger dERNs during the Flanker task than during the RL task, but this was not true for worriers or for non-anxious participants. This finding, along with the other differences in the way the OC group responded to the tasks in Experiment 1 suggest that there was a difference in how people in the OC group experienced the RL task This difference cannot be attributed to the high level of anxious anticipation in the OC group because the high worry group did not show the same effect. Other factors that might explain

why people with OC symptoms produced dERNs with different amplitudes during the two tasks should be explored in future studies. However, it should be noted that the worriers did not show an enhanced dERN in the Flanker task which was inconsistent with previous research on worriers. That null effect limits confidence somewhat in the dissociation between the OC and worry group's dERNs on the RL task. In order to be confident that people with OC symptoms really respond differently, replication of this effect may be necessary.

Some studies have shown that people with OCD have meta-memory deficits. It was hypothesized that lower level of cognitive confidence might contribute to the uncertainty that people with OC symptoms feel during the RL task and therefore contribute to the difference in dERN between the Flanker and RL tasks for people with OC symptoms. In order for this to be a viable mechanism to explain the decreased ERN in people with OC symptoms during learning tasks, it should be present just for participants with OC symptoms and not for worriers or non-anxious people. The results of Experiment 1revealed a deficit in cognitive confidence in people who report OC symptoms, but not for those who report more general worry symptoms. It follows that the OC participants' lower level of cognitive confidence may be the factor that leads them to feeling more uncertain about their performance during the RL task. Consistent with this idea, the OC group reported feeling less uncertain about their responses during the Flanker task than during the RL task, but there was no such difference in uncertainty for the worriers or non-anxious participants. Additionally, OC people were actually worse at identifying when they correctly responded during the RL task than during the Flanker task.

Only the OC group reported a decreased level of cognitive confidence. OC participants were also more uncertain about their responding on the RL task, and produced smaller dERNs. Therefore, the relationship between OC symptoms, reported uncertainty during the tasks, and dERN amplitude during the two tasks was evaluated. Higher scores on the measure of OC symptoms did predict a larger dERN on the Flanker task compared with the RL task, however when participants' reported uncertainty during the RL task was included in the regression, the original relationship was not mediated by task uncertainty. Additionally, participants' self-reported OC symptoms were not a significant predictor of their reported uncertainty during the RL task. This failure to find mediators of the relationship could be due to insufficient power or it could be due to a true lack of a relationship between these variables. Since the variables were generally related to each other in the expected direction the relationship between how uncertain participants feel about their performance on the RL task and the dERN that was produced during the task was further explored in Experiment 2. It examined the question of whether the level of uncertainty could be manipulated in non-anxious people during a learning task and if so, would that have the predicted effect on their dERNs.

Several previous studies have found that asking non-anxious participants to repeatedly perform checks produces a decrease in their confidence of the memory for the thing being checked (Alcolado & Radomsky, 2011; Radomsky, Gilchrist, & Dussault, 2006). Radomsky and Alcolado (2010) have found that this effect held for things that are mentally checked and not just for physically checked items. Given these findings, a modification was made to the learning task that asked participants to report how uncertain they were about their previous response in order to have them

mentally check their accuracy in a similar way to a person with OC sympoms might check. This manipulation was designed to make the non-anxious participants more uncertain about the accuracy of their responses. However, the checking task actually ended up having the opposite effect. Self-reported uncertainty increased during the task. Since the manipulation failed and uncertainty levels were not lowered by the manipulation, it was not surprising that there was no difference in the dERNs between the checking task and the regular leaning task that did not include checking.

Interestingly, there were behavioral difference in how participants responded in the two tasks. Those in the checking condition responded more slowly and were better able to identify when they responded correctly. It may be that the checking condition caused people to value accuracy over speed and slow their responses accordingly. Also, the checking may have made them pay more attention to the accuracy of their responses which improved their ability to identify correct responses. Previous studies have shown that when accuracy was prioritized in a Flanker task, participants tended to respond more slowly (Gehring, Goss, Coles, Meyer, & et al., 1993). The checking manipulation may have sent the message that accuracy was more important than speed during the task which could have resulted in slower responses during the checking task. However, if that had been the case, it should also have impacted the dERN. Although the manipulation was not successful in creating uncertainty in the non-anxious people, another way to examine the role of uncertainty in the amplitude of the dERN in learning tasks was attempted with Experiment 3.

Experiment 3 aimed to decrease the anxious participants' level of uncertainty during the RL task by providing instructions to the task, and explored what effect that decrease in uncertainty would have on their dERNs. As to the first question, there was

no difference in uncertainty between the conditions or between anxiety groups. Likewise, there was no difference in participants' ability to detect when they had correctly responded for either condition or group. This pattern of results might suggest that the instruction manipulation failed or at least that the measures used to assess uncertainty were not sensitive enough to pick up any change in uncertainty related to the instruction manipulation. The measure may not have been sensitive enough to detect a difference due to the fact that overall levels of reported uncertainty were low, and uncertainty might have been at a floor level preventing any differences from being found.

Interestingly, larger dERNs were found during the instructed task than the regular task, but that effect was not moderated by the participant's level of anxiety. Both anxious and non- anxious participants produced larger dERNs during the instructed task than during the regular task. This finding suggests that when participants were clear about how they were supposed to respond, there was a more serious violation of expectation, and thus a larger dERN when a mistake was made.

Additionally, participants were more accurate during the instructed task than during the regular task. This finding supports the idea that the instruction manipulation was successful in helping the participants to respond more accurately during the instructed task, however it was unclear whether there was a corresponding increase in the participant's feeling of uncertainty about their responses. Since participants were more accurate during the instructed task, their increased dERNs in that task could be due to the fact that they were making fewer errors. ERNs tend to be larger during conditions with higher levels of accuracy.

Overall, the findings from these three studies provide modest support the hypothesis that the participants with OC symptoms are feeling more uncertain about the accuracy of their responses during learning tasks which may result in smaller ERNs, and it should be noted that this effect was specific to people with OC symptoms and does not generalize to people with anxiety more broadly. This modest support comes primarily from the findings of the first experiment.

The subsequent two experiments attempted to manipulate uncertainty in different ways, and in both experiments the manipulations failed. These failed manipulations limit the conclusions that can be drawn from the studies. Additionally, another major limitation of these studies was that they were conducted with an undergraduate sample as opposed to a clinical sample. It would be helpful in the future to attempt to replicate the results of Experiment 1 in a patient population in order to confirm that the effects seen as being specific to the OC group truly are specific, and that the lack of effect in worriers was not due to it being a non-clinical sample. Another future direction for this research would be to try different manipulations to change participant's uncertainty about the accuracy of their responses, as that would be a stronger test of uncertainty being a mechanism than the present experiments. Possible manipulations could include making the task more challenging by adding more stimuli, changing the stimulus-response mappings to be less than 100%, or decreasing the time to respond. It would also be helpful to develop a more sensitive measure of participants' feeling of uncertainty during the task than the 5 point scale used here since there appears to have been a ceiling effect on that measure in at least one of the experiments. On the other hand, if the failures of Experiments 2 and 3

indicate that uncertainty during the task is not relevant then other factors could be explored as mediators of this relationship such as perfectionism.

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Appendix A

MEASURES

Obsessive–Compulsive Inventory—Revised (OCI-R)

The following statements refer to experiences that many people have in their everyday lives. Circle the number that best describes HOW MUCH that experience has DISTRESSED or BOTHERED you during the PAST MONTH. The numbers refer to the following verbal labels:

0	1	2	3	4
Not at all	A little	Moderately	A lot	Extremely

1. I have saved up so many things that they get in the way.
2. I check things more often than necessary.
3. I get upset if objects are not arranged properly.
4. I feel compelled to count while I am doing things.
5. I find it difficult to touch an object when I know it has been touched by strangers or certain people.
6. I find it difficult to control my own thoughts.
7. I collect things I don't need.
8. I repeatedly check doors, windows, drawers, etc.
9. I get upset if others change the way I have arranged things.
10. I feel I have to repeat certain numbers.
11. I sometimes have to wash or clean myself simply because I feel contaminated.
12. I am upset by unpleasant thoughts that come into my mind against my will.
13. I avoid throwing things away because I am afraid I might need them later.
14. I repeatedly check gas and water taps and light switches after turning them off.
15. I need things to be arranged in a particular order.
16. I feel that there are good and bad numbers.
17. I wash my hands more often and longer than necessary.
18. I frequently get nasty thoughts and have difficulty in getting rid of them.

Beck Depression Inventory-II (BDI-II)

This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the ONE STATEMENT in each group that best describes the way you have been feeling during the PAST TWO WEEKS, INCLUDING TODAY. Circle the number beside the statement you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group. Be sure that you do not choose more than one statement for any group.

1
0 I do not feel sad
1 I feel sad much of the time
2 I am sad all the time
3 I am so sad or unhappy that I can't stand it.

2
0 I am not discouraged about my future
1 I feel more discouraged about my future than I used to be.
2 I do not expect things to work out for me.
3 I feel my future is hopeless and will only get worse.

3
0 I do not feel like a failure.
1 I have failed more than I should have.
2 As I look back, I see a lot of failures.
3 I feel I am a total failure as a person.

4
0 I get as much pleasure as I ever did from the things I enjoy.
1 I don't enjoy things as much as I used to.
2 I get very little pleasure from the things I used to enjoy.
3 I can't get any pleasure from the things I used to enjoy.

5
0 I don't feel particularly guilty
1 I feel guilty over many things I have done or should have done.
2 I feel guilty most of the time.
3 I feel guilty all of the time.

6
0 I don’t feel I am being punished.
1 I feel I may be punished.
2 I expect to be punished.
3 I feel I am being punished.

7
0 I feel the same about myself as ever
1 I have lost confidence in myself.
2 I am disappointed in myself.
3 I dislike myself.

8 0 I don't criticize or blame myself more than usual.
1 I am more critical of myself than I used to be.
2. I criticize myself for all of my faults.
3 I blame myself for everything bad that happens.

9 0 I don't cry any more than I used to.
1 I cry more than I used to.
2 I cry over every little thing.
3 I feel like crying, but I can't.

10 0 I am no more restless or wound up than usual.
1 I feel more restless or wound up than usual.
2 I am so restless or agitated that it's hard to stay still.
3 I am so restless or agitated that I have to keep moving or doing something.

11 0 I have not lost interest in other people or activities.
1 I am less interested in other people or things than before.
2 I have lost most of my interest in other people or things.
3 It's hard to get interested in anything.

12 0 I make decisions about as well as ever.
1 I find it more difficult to make decisions than usual.
2 I have much greater difficulty in making decisions than I used to.
3 I have trouble making any decisions.

13 0 I do not feel I am worthless.
1 I don't consider myself as worthwhile and useful as I used to.
2 I feel more worthless as compared to other people.
3 I feel utterly worthless.

14 0 I have as much energy as ever.
1 I have less energy than I used to have.
2 I don't have enough energy to do very much.
3 I don't have enough energy to do anything.

15 0 I have not experienced any change in my sleeping pattern
1 I sleep somewhat more/less than usual
2 I sleep a lot more/less than usual
3 I sleep most of the day/I wake up 1-2 hours early and can't get back to sleep

16 0 I am no more irritable than usual
1 I am more irritable than usual
2 I am much more irritable than usual

3 I am irritable all the time.

17 0 I have not experienced any change in my appetite.
1 My appetite is somewhat greater/less than usual.
2 My appetite is much greater/less than usual.
3 I crave food all the time/I have no appetite at all.

18 0 I can concentrate as well as ever.
1 I can't concentrate as well as usual.
2 It's hard to keep my mind on anything for very long.
3 I find I can't concentrate on anything.

19 0 I am no more tired or fatigued than usual.
1 I get more tired or fatigued more easily than usual.
2 I am too tired or fatigued to do a lot of the things I used to do.
3 I am too tired or fatigued to do most of the things I used to do.

20 0 I have not noticed any recent change in my interest in sex.
1 I am less interested in sex than I used to be.
2 I am much less interested in sex now.
3 I have lost interest in sex completely.

The Penn State Worry Questionnaire (PSWQ)

Instructions: Rate each of the following statements on a scale of 1 (“not at all typical of me”) to 5 (“very typical of me”). Please do not leave any items blank.

1 2 3 4 5

Not at all typical Very typical of me

1. If I do not have enough time to do everything, I do not worry about it.
2. My worries overwhelm me.
3. I do not tend to worry about things.
4. Many situations make me worry.
5. I know I should not worry about things, but I just cannot help it.
6. When I am under pressure I worry a lot.
7. I am always worrying about something.
8. I find it easy to dismiss worrisome thoughts.
9. As soon as I finish one task, I start to worry about everything else I have to do.
10. I never worry about anything.
11. When there is nothing more I can do about a concern, I do not worry about it anymore.
12. I have been a worrier all my life.
13. I notice that I have been worrying about things.
14. Once I start worrying, I cannot stop.
15. I worry all the time.
16. I worry about projects until they are all done.

Meta-Cognitions Questionnaire (MCQ) – Cognitive Confidence Sub-Scale

This questionnaire is concerned with beliefs people have about their thinking. Listed below are a number of beliefs that people have expressed. Please read each item and indicate how much you generally agree with it by circling the appropriate number. Please respond to all of the items, there are not right or wrong answers.

1	2	3	4
Do Not Agree	Agree Slightly	Agree Moderately	Agree Very Much

1. I have difficulty knowing if I have actually done something, or just imagined it.
2. I have little confidence in my memory for words and names.
3. My memory can mislead me at times.
4. I have a poor memory.
5. I imaging having not done things, and then doubt my memory for doing them.
6. I am easily distracted.
7. I have little confidence in my memory for places.
8. I do not trust my memory.
9. I have little confidence in my memory for actions.
10. I have difficulty keeping my mind focused on one thing for a long time.

Appendix B

IRB APPROVALS

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE: October 16, 2013

TO: Emily Stanley, M.A.
FROM: University of Delaware IRB

STUDY TITLE: [513385-1] Error-Related Brain Activity in Anxious People during Probabilistic Learning and Response Conflict Tasks
IRB REFERENCE #:
SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: October 7, 2013
EXPIRATION DATE: October 6, 2014
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # *4, 7*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE: June 17, 2013

TO: Emily Stanley, M.A.
FROM: University of Delaware IRB

STUDY TITLE: [480154-1] Inducing Uncertainty in Non-Anxious People during a Reinforcement Learning Task: An Event-Related Potential Study

SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: June 17, 2013
EXPIRATION DATE: June 16, 2014
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # 4, 7

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

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Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Jody-Lynn Berg at (302) 831-1119 or jlberg@udel.edu. Please include your study title and reference number in all correspondence with this office.

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE: April 29, 2013

TO: Emily Stanley, M.A.
FROM: University of Delaware IRB

STUDY TITLE: [457974-1] The Effect of Uncertainty on the Magnitude of Error-Related Brain Activity in Anxious People during a Probabilistic Learning Task

SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: April 29, 2013
EXPIRATION DATE: April 28, 2014
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # 7

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

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Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Jody-Lynn Berg at (302) 831-1119 or jlberg@udel.edu. Please include your study title and reference number in all correspondence with this office.