The Effect of Manipulating Task Difficulty on Error-Related Negativity: Divergence between Reinforcement Learning and Error of Commission Tasks

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Dedication

This thesis is dedicated to my family.

Abstract

Previous research has found that individuals with obsessive-compulsive (OC) traits show larger error-related negativity (ERN) and correct-response negativity (CRN) amplitudes than controls during error of commission tasks, such as the flanker task. However, a recent study found that individuals with OC tendencies showed smaller ERN amplitudes during a probabilistic learning task. A probabilistic learning task uses a reinforcement learning paradigm in which correct responses are reinforced a certain percentage of the time; therefore, the correct choice is less obvious in a probabilistic learning task than in a flanker task. This study hypothesized that uncertainty regarding the correct response may moderate ERN and CRN amplitudes in both the probabilistic learning task and the flanker task. In addition, individuals with OC traits were predicted to show smaller ERN and CRN amplitudes when the task was difficult. These hypotheses were tested by manipulating the uncertainty of both the probabilistic learning task and the flanker task. The results of this study show that the level of uncertainty during the probabilistic learning task had little effect on ERN or CRN amplitudes, suggesting that the smaller amplitudes found during probabilistic learning are not due to the difficult nature of the task. Additionally, individuals with high OC traits show attenuated ERN and CRN amplitudes during the difficult flanker task. The results of this study suggest that task uncertainty may moderate response monitoring processes during motor errors of commission but not during reinforcement learning paradigms.

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1. Introduction:

Obsessive-compulsive disorder (OCD) is a chronic and debilitating anxiety disorder characterized by obsessions and compulsions. Obsessions are intrusive and persistent thoughts, images, or impulses that cause significant distress and compulsions are repetitive behaviors or mental acts which are aimed at reducing the anxiety associated with obsessions (American Psychiatric Association, 2000). The purpose of the present study is to use electrophysiological measures to investigate performance monitoring in a group of individuals with obsessive-compulsive symptoms. Previous research has implicated several neural structures that may be important in the development of OCD. OCD is thought to be associated with an impaired cortical-striatal-thalamic-cortical circuit in the brain. Neuroimaging studies find excessive activity in the orbitofrontal cortex, the anterior cingulate cortex (ACC), the thalamus, the striatum, and the caudate nucleus in adults with OCD (Adler et al., 2000; Breiter & Rauch, 1996; Cottraux et al., 1996; Fitzgerald et al., 2005; Mataix-Cols et al., 2004; McGuire et al., 1994; Menzies et al., 2008; Phillips et al., 2000; Rauch et al., 1994; Rotge et al., 2008; Schienle, Walter, Schaefer, Stark, & Vaitl, 2005; Shapira et al., 2003; Simon, Kaufmann, Müsch, Kischkel, & Kathmann, 2010; Ursu, Stenger, Shear, Jones, & Carter, 2003; van den Heuvel et al., 2005; Whiteside, Port, & Abramowitz, 2004) and similar abnormalities have been found in the prefrontal-striatal-thalamic circuit in pediatric populations with OCD (for an overview, see Huyser, Veltman, de Haan, & Boer, 2009).

Current theory suggests that the cortical-striatal-thalamic-cortical circuit forms a feedback loop that is hyperactive in individuals with OCD and may contribute to the symptoms of this disorder (Gehring, Himle, & Nisenson, 2000). This circuit is thought to play a role in goal-directed behavior such as performance monitoring. Conflict between internal and external standards when goals are not met has been hypothesized to result in an enhanced error signal in individuals with OCD (Pitman, 1987). Therefore, excessive activity in this circuit may lead to a feeling of incompleteness that could impair the ability to judge whether one's performance was satisfactory or not. This may contribute to the feelings of uncertainty that fuel compulsions in OCD (e.g. checking and rechecking). However, the exact relationship between excessive activity in the cortical-striatal-thalamic-cortical circuit and OCD symptoms is still speculated.

To test the hypothesis that OCD is associated with hyperactive error signals, previous research has used error-related negativity (ERN), a negative-polarity electrophysiological signal that occurs about 80-100 ms after an error of motor commission, i.e. responding incorrectly (Gehring, Goss, Coles, Meyer, & Donchin, 1993). Research has repeatedly found enhanced ERN amplitudes in OCD patients compared to healthy controls (Endrass, Klawohn, Schuster, & Kathmann, 2008; Gehring et al., 2000; Johannes et al., 2001; Ruchsow et al., 2005; but also see Nieuwenhuis, Nielen, Mol, Hajcak, & Veltman, 2005) and this has been replicated in nonclinical populations including adults with obsessive-compulsive traits (Gründler, Cavanagh, Figueroa, Frank, & Allen, 2009; Hajcak & Simons, 2002) and children with obsessive-compulsive behaviors (Santesso, Segalowitz, & Schmidt, 2006). The ERN is thought to be generated by the ACC and this has been supported using lesion studies (Stemmer, Segalowitz, Witzke, & Schönle, 2003), dipole source localization (van Veen & Carter, 2002), and functional Magnetic Resonance Imaging (fMRI) studies (Ursu et al., 2003; Ullsperger & von Cramon, 2004; Debener et al., 2005; Fitzgerald et al., 2005; Maltby, Tolin, Worhunsky, O'Keefe, & Kiehl, 2005). In summary, individuals with OCD appear to have larger ERN amplitudes than healthy controls, which has been interpreted as evidence of a hyperactive performance monitoring system. Additionally, there is evidence that the ERN is generated by the ACC, a region where individuals with OCD show excessive activity.

Despite the association between OCD and larger ERN amplitudes, Nieuwenhuis et al. (2005) found no significant differences in the electrophysiological responses to errors between individuals with obsessive-compulsive traits and healthy controls when using a probabilistic learning task. A probabilistic learning task uses a reinforcement learning paradigm in which participants are shown two symbols and must learn to choose the correct symbol based on feedback. The correct response is reinforced (participants are told they are "correct") a certain percentage of the time depending on the symbol pair, e.g. 50, 80, or 100 percent of the time (Nieuwenhuis et al., 2005). A limitation to the study design used by Nieuwenhuis et al. (2005) is that feedback was provided for each trial. Feedback reduces the participants' need to self-monitor their response accuracy, which may be necessary for the generation of the ERN (Nieuwenhuis et al., 2005). Therefore, the lack of a significant difference between the obsessive-compulsive group and controls may be due to the participants' expectation of receiving feedback after each trial.

A study by Gründler et al. (2009) was able to overcome the limitation of the Nieuwenhuis et al. (2005) study by using a version of the probabilistic learning task that includes a "test" phase where participants must choose the correct symbol based on what they have learned earlier without receiving any feedback on their performance. Gründler et al. (2009) found that individuals with obsessive-compulsive symptoms showed smaller ERN amplitudes than controls during the probabilistic learning task. The unexpected finding of smaller ERN amplitudes in an obsessive-compulsive group was replicated in a second study by the same authors using an independent sample (Gründler et al., 2009). The authors note that studies that find an association between OCD and enhanced ERN amplitudes typically use response conflict tasks such as the flanker task, the Stroop task, the Simon task, and the Go/NoGo task. The authors suggest that the ERN elicited during a response conflict task may be different from the ERN found during a probabilistic learning task and they support this by citing fMRI data showing that the ERN in each task is generated from two distinct but overlapping neural mechanisms (Gründler et al., 2009).

However, it is also possible that the response conflict task and the probabilistic learning task do not show similar results because the level of uncertainty in each task is not equivalent. A critical difference between a response conflict task, like the flanker task, and a probabilistic learning task is that in the flanker task the feedback is explicit; there is always a clearly correct or incorrect response. In the probabilistic learning task, the correct choice is less obvious because accurate feedback is provided only a certain percentage of the time. Therefore, there is more uncertainty regarding the correct and incorrect responses inherent in the probabilistic learning task. The degree of confidence participants have that an error was actually committed may be a crucial factor in explaining the unusual results found by Nieuwenhuis et al. (2005) and Gründler et al. (2009) during the probabilistic learning task.

Research suggests that uncertainty in a task attenuates the amplitude of the ERN (Pailing & Segalowitz, 2004). The research by Pailing and Segalowitz (2004) supports the notion that participants may show smaller ERN amplitudes during the probabilistic learning task due to the uncertainty that is intrinsic to this task. Furthermore, this uncertainty may be more detrimental to those with OCD, which is supported by research showing that OCD patients are less adaptable to uncertainty than controls (Tolin, Abramowitz, Brigidi, & Foa, 2003; Holaway, Heimberg, & Coles, 2006). If OCD patients are affected by uncertainty to a greater extent than controls, then we might expect individuals with OCD to show a significantly smaller ERN during a difficult task like the probabilistic learning task. Current theory holds that those with OCD have a hyperactive, or overactive, error-monitoring circuit regardless of the task. However, this study hypothesizes that performance monitoring is hyperactive in those with OCD when there is a clearly correct response and hypoactive, or less active, when the correct response is ambiguous.

Additionally, this study will explore the relationship between obsessive-compulsive symptoms and a second ERP of interest, the correct-response negativity or CRN. The CRN is a negative-polarity electrophysiological signal that occurs about 80-100 ms after a correct response (Ford, 1999; Vidal, Burle, Bonnet, Grapperon, & Hasbroucq, 2003; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). The CRN is similar to the ERN, but is it typically smaller in amplitude, it does not occur as reliably, and its functional significance is not yet known (Endrass et al., 2008). Currently, the CRN is thought to reflect partial error processing of correct trials (Endrass et al., 2008). Research has demonstrated that individuals with obsessive-compulsive symptoms show enhanced negative amplitudes following correct and incorrect trials, which suggests that those with OCD may show excessive performance monitoring regardless if an error is made or not (Endrass et al., 2008; Hajcak & Simons, 2002). These results are reported in a limited number of studies; therefore, replication is necessary to substantiate these findings. Based on research showing enhanced CRN amplitudes following correct trials in high obsessive-compulsive participants, the present study will investigate whether CRN amplitudes differ between the high and low obsessive-compulsive groups in this study and whether task uncertainty has an effect on CRN amplitudes.

The aims of the current study are 1) to investigate the hypothesis that the uncertainty of the task moderates the amplitude of the ERN in the flanker and probabilistic learning paradigms, 2) to explore the effect of uncertainty on performance monitoring in individuals with obsessive-compulsive traits, and 3) to examine the relationship between obsessive-compulsive symptoms and CRN amplitudes. The first aim will be tested by manipulating the degree of uncertainty for the correct response in the flanker and probabilistic learning tasks. Making the flanker task more difficult (increasing uncertainty) is hypothesized to result in attenuated ERN amplitudes. Modifying the probabilistic learning task so that the correct response is more explicit (decreasing uncertainty) is predicted to increase ERN amplitudes. Such a result would suggest that the smaller ERN amplitudes found in the probabilistic learning task are due in part to the uncertainty associated with this task.

The second aim of this study will be tested by comparing the effect of uncertainty on ERN amplitudes in those with high or low obsessive-compulsive symptoms. Individuals with OCD traits are predicted to be affected by the uncertainty of the task to a greater extent than controls and are hypothesized to show significantly smaller ERN amplitudes when the task is difficult. If this were the case, it would suggest that those with OCD symptoms might have an impaired ability to respond adaptively when the correct response is ambiguous. Such a finding would provide novel evidence suggesting that OCD is associated with an overly active performance monitoring system when there is a clearly correct response and a less active, inefficient system when the correct response is ambiguous.

The third aim will be investigated by comparing CRN amplitudes between the high and low obsessive-compulsive participants. This study predicts that the high obsessive-compulsive group will show larger CRN amplitudes than the low obsessive-compulsive group. Such results would replicate previous research showing enhanced CRN amplitudes in OCD and would support the notion that OCD is associated with a hyperactive performance monitoring system regardless of whether a response is correct or incorrect rather than a hyperactive error-only monitoring system which was originally suggested by Gehring et al. (2000). If obsessive-compulsive participants show enhanced CRN amplitudes, than it is predicted that these event-related potentials will also be affected by task uncertainty, such that CRN amplitudes are expected to be attenuated during difficult tasks.

2. Methods:

2.1 Participants

Participants included 118 adults (82 females, 36 males) whose ages ranged from 18 to 30 years of age. This study was approved by the University of Minnesota Institutional Review Board and informed consent was obtained from all participants. Participants received extra credit in an introductory course for their participation. Participants were selected based on their responses to the Obsessive-Compulsive Inventory- Revised (OCI-R), a 18-item questionnaire that measures six dimensions of OCD symptoms including washing, obsessing, hoarding, ordering, checking and neutralizing (Foa et al., 2002). This scale can be used to screen for the frequency of obsessive-compulsive symptoms and to measure symptom severity using a 5-point Likert scale of subjective distress.

The OCI-R has been shown to have adequate psychometric properties in both clinical and nonclinical samples (Fullana et al., 2005; Hajcak, Huppert, Simons, & Foa, 2004; Huppert et al., 2007). The present study adopts Foa et al.'s (2002) recommendation that a clinically significant cutoff is an OCI-R score of 21 or greater. A total of 415 undergraduates completed the OCI-R using a secure online survey. From these 415 students, 118 students met the criteria for this study and were recruited for the EEG recording session based on their total OCI-R score. Using the criterion suggested by Foa et al. (2002), two similarly sized groups were selected: a high obsessive-compulsive group (OCI-R ≥ 21) consisting of 58 individuals (41 females, 17 males) and a low obsessive-compulsive group (OCI-R ≤ 20) composed of 60 individuals (41 females, 19 males). Table 1 shows the demographics for the high and low obsessive-compulsive groups. Foa et al.'s (2002) recommended cutoff score of 21 on the OCI-R does not imply that an individual with a score of 21 or greater would be diagnosed with OCD; instead, a score of 21 or greater suggests that the participant endorses obsessive-compulsive symptoms to a greater extent than expected in a healthy sample. After the initial recruitment, each subject was assigned an identification number, which allowed the experimenter to be blind to group membership until the data reduction was finished. All participants had normal or corrected-to-normal vision and hearing and no history of a major neurological or psychiatric condition. Participants were excluded if they were currently using psychoactive medications or if they did not perform above chance level during the probabilistic learning task.

Table 1: Group characteristics for the high and low obsessive-compulsive groups

	Low obsessive-compulsive	*High obsessive-compulsive*
Sample size (females, males)	60 (41,19)	58 (41,17)
Age in years	19.95 (1.99)	19.47 (1.46)
OCI-R	9.40* (5.92)	30.51* (8.21)
BDI	6.74* (6.56)	13.42* (9.86)
Flanker Test Accuracy	0.79 (0.12)	0.82 (0.11)
Flanker Response Time	302.33 (46.76)	309.71 (45.38)
PL Test Accuracy	0.59 (0.10)	0.61 (0.05)
PL Response Time	329.75 (52.26)	335.15 (38.33)

Group means and (standard deviations) are reported; Significant mean differences ($p < .05$) are denoted with an asterisk.

2.2 Procedure

Recruitment materials provided a general description of the study but did not explain the study's purpose or hypotheses. Participants completed several questionnaires using a secure online website prior to the session. Questionnaires included the OCI-R (Foa et al., 2002), the Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990), the Mood and Anxiety Symptom Questionnaire (Watson et al., 1995a; Watson et al., 1995b), and the Beck Depression Inventory (Beck & Steer, 1987). Those invited to complete the physiological recording portion of this study were asked to come in for a single 90 minute recording session. No participants discontinued their participation after informed consent was obtained. After placement of the EEG electrodes, participants were seated 100 cm in front of a LCD monitor and given detailed task instructions. Participants completed three tasks: a flanker task, a resting task (data not reported in this paper), and a probabilistic learning task. All tasks were presented using E-Prime software and response accuracy and reaction times were recorded with a subject response box. At the end of the tasks, participants provided subjective ratings of difficulty for each task and then were debriefed about the purpose of the study.

2.3 Flanker task

A modified version of the flanker task was presented (Eriksen & Eriksen, 1974). During the flanker task, participants are instructed to respond as quickly and accurately as possible to the center letter while ignoring the surrounding letters. Trials begin with a fixation cross for 500 ms followed by a string of letters (e.g. RRBRR). Participants were required to make speeded responses by pressing one button when they see a particular center letter (e.g. "R") and pressing another button when they see a different center letter (e.g. "B"). Trials during this particular task can be congruent (flankers and center letter are the same; e.g. RRRRR or BBBBB) or incongruent (flankers and center letter differ; e.g. RRBRR or BBRBB). There were five types of stimuli used during this task: EEFEE, OOQOO, MMNMM, RRBRR, and VVWVV. Participants completed two practice blocks of 20 trials followed by 10 blocks (two blocks per letter string type) of 40 trials (400 total trials) with each block initiated by the subject. Consecutive blocks of the same letter strings were presented so that the correspondence between the correct button and center letter could be balanced (i.e. if the first block mapped the letter "R" to the right button, then during the second block "R" would be mapped to the left button).

In order to test the hypotheses of this study, two versions of the flanker task were used, each with a different level of difficulty. Based on participants' subjective ratings of task uncertainty, these two versions of the flanker task will be referred to as the "easy" and "difficult" flanker tasks. Half the participants completed the easy version and the other half completed the difficult version but participants were not informed that there were two versions of the task until the debriefing. During the easy flanker task, the stimuli were presented in a white font on a black background for 500 ms and participants were allowed up to 800 ms to make their response. The five letter strings used in the easy and difficult flanker tasks were identical. However, for the difficult flanker task, the stimuli were degraded by presenting the letters in a gray font on a black background. Furthermore, the duration of the stimuli presentation was shorter (200 ms) and the participants were allowed only 500 ms to make their response. The subjective ratings of difficulty were significantly higher for the participants who completed the difficult flanker task than for those who completed the easy flanker task ($t(116) = 9.13$, $p < .001$, see table 2 for descriptive statistics for each task). In both versions of the flanker task, if participants missed the response deadline, then "no response detected" was displayed for 500 ms. No other feedback was given. The inter-trial-interval was jittered, varying between 200 and 500 ms.

Table 2: Descriptive statistics for each task

	Flanker		*Probabilistic Learning*	
	Easy	Difficult	Easy	Difficult
Subjective rating of difficulty	3.38 (1.83)*	6.25 (1.58)*	6.58 (2.19)*	8.29 (1.53)*
Accuracy	0.88 (0.07)*	0.72 (0.10)*	0.62 (0.07)	0.60 (0.10)
Response Time	285.41 (48.77)*	326.50 (32.23)*	324.17 (41.65)	329.02 (40.71)

Means and (standard deviations) are reported; Significant mean differences ($p < .05$) are denoted with an asterisk.

2.4 Probabilistic learning task

The probabilistic learning task used in this study is a variation of the task used by Frank, Woroch, & Curran (2005). As mentioned previously, the probabilistic learning task uses a reinforcement learning paradigm in which participants are shown two symbols and must learn to choose the correct symbol based on feedback. The correct response is reinforced (participants are told they are "correct") a certain percentage of the time depending on the symbol pair (see figure 1). The probabilistic learning task consists of a training phase and a test phase. During the training phase, trials begin with a fixation cross for 500 ms followed by one of three different pairs of symbols (which will be referred to as AB, CD, and EF) presented for 600 ms and subjects have 1000 ms to respond. Participants are instructed that for each pair of symbols, one of the symbols has a higher chance of being correct than the other and they must learn this association through trial and error. Participants press one button to choose the symbol on the right side of the screen or another button to choose the symbol on the left. The position of the correct symbol (left or right side of the screen) was balanced within each block. Following the subject's response, s/he is given immediate feedback ("correct," "incorrect," or "no response detected") for 500 ms. The inter-trial-interval is jittered between 600 and 700 ms.

The probability that a symbol will be reinforced (participants are told they are correct) is different for each symbol. Based on the probabilistic feedback, participants should learn to choose A over B, C over D, and E over F (see figure 1). The training phase consists of up to 6 blocks of 60 trials (136 trials total) but participants can skip the remaining training blocks and advance to the test phase once they are able to choose the correct symbol above a certain percentage of the time (A over B ≥ 65%, C over D ≥ 60%, and E over F ≥ 50%). After the sixth training phase, if these criteria were not met participants were still allowed to advance to the test phase. During the test phase, the six symbols were presented in new pair combinations without feedback for a total of 120 trials. Each new pair had an optimal and a suboptimal response based on the previously defined probabilities of being correct. The test phase allows for the investigation of two types of learning: Go learning (learning that responding to a certain symbol is correct) versus NoGo learning (learning that responding to a particular symbol is incorrect). If participants learn more from Go learning, then they would be expected to choose A over C, D, E and F but if participants learn from NoGo learning, the they would be expected to choose C, D, E and F over B (Frank et al., 2005). This distinction is important for the current study because the ERN amplitude is associated with NoGo learning but not with Go learning (Gründler et al., 2009).

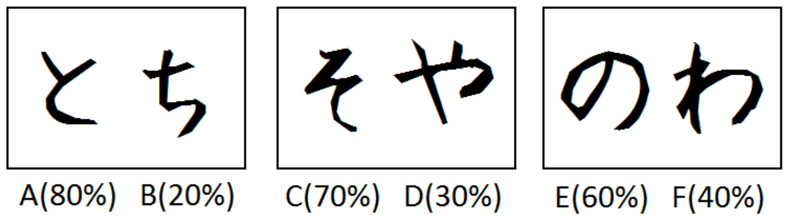

Figure 1: The probabilistic learning task stimuli consist of pairs of Hiragana characters. Participants are instructed to choose the symbol with the highest chance of being correct. During the training phase, participants receive probabilistic feedback each time they choose a symbol. For example, in the first pair, if the participant chooses the first symbol, they will be told they are "correct" 80 percent of the time. During the testing phase, participants see new combinations of the same symbols and they do not receive feedback. The letters and probability percentages below each symbol pair are not presented to subjects.

Like the flanker task, the probabilistic learning task was modified in terms of difficulty level to test the hypotheses of this study. In the probabilistic learning tasks used by Frank et al. (2005) and Gründler et al. (2009), the probability that a symbol is correct was as follows: A (80%) vs. B (20%), C (70%) vs. D (30%), and E (60%) vs. F (40%). These exact probabilities were retained for one version of the probabilistic learning task used in the current study. Based on participants' subjective ratings of task difficulty, this task will be referred to as the "difficult" probabilistic learning task. For the "easy" probabilistic learning task, the probabilities were changed to A (100%) vs. B (0%), C (95%) vs. D (5%), and E (90%) vs. F (10%) in order to make the correct choice more explicit. Half the participants completed the difficult probabilistic learning task and the other half completed the easy probabilistic learning task. The new version of the probabilistic learning task with more explicit correct choices was rated by participants as being significantly less difficult than the original version ($t(115) = -4.88$, $p < .001$, see table 2 for uncertainty means).

For both the easy and the difficult versions of the probabilistic learning task, learning was determined in two ways. First, as mentioned previously, during the training phase there are up to six blocks of trials and participants can skip the remaining training blocks and advance to the test phase once they are able to choose the correct symbol above a certain percentage of the time (A over B $\geq$ 65%, C over D $\geq$ 60%, and E over F $\geq$ 50%). Participants that are allowed to advance to the test phase using these criteria have demonstrated learning of the probabilities in this task. However, as mentioned earlier, participants who reach the sixth training block and who have not yet demonstrated the learning criteria are still allowed to advance to the test phase. Therefore, a second criterion of learning is based on accuracy levels during the test phase. Participants who were unable to choose the correct symbol above chance levels during the test phase were excluded from data analysis. Mean accuracy levels and response times for each task are shown in table 2. Ten participants (5 low OC, 4 high OC) were excluded from data analysis because their accuracy was 50 percent or less, suggesting they were unable to learn the probabilities during the task. Accuracy levels were not significantly different between the easy and difficult versions of the probabilistic learning task ($t(116) = 1.26$, $p = .60$).

2.5 Psychophysiological recording and data analysis

EEG data and electroocculographic (EOG) activity were recorded continuously from 128 electrodes using a Geodesics Sensor Cap (Electrical Geodesics Inc., Eugene, OR). The Geodesics Sensor Cap does not use the standard 10-20 system of electrode placement (see figure 2); however, several EGI electrode locations have been equated to the common 10-20 electrode sites (Luu & Ferree, 2005). Reference was recorded online using the average reference electrode, which corresponds to Cz in the 10-20 system (Luu & Ferree, 2005). Impedances were below 10 kΩ. Data were amplified (bandpass filter of 0.01 to 100 Hz) and digitized with a sampling rate of 250 Hz using EGI amplifiers. Offline, EOG artifacts were corrected using independent components analysis. Other artifacts in the data including muscle activity were removed using visual inspection. The data were re-referenced to the average reference of all the electrodes. Epochs were extracted with a duration of 200 ms before and 500 ms after each response. Response-locked epochs were averaged separately for correct and incorrect trials during the flanker task and for suboptimal and optimal choices during the test phase of the probabilistic learning task. Epochs were filtered with a 20 Hz low-pass filter. Based on methods used in previous studies, ERP amplitudes were determined from peak-to-trough measurements to avoid amplitude differences due to different baselines between groups or conditions (Gründler et al., 2009; Frank et al., 2005).

As mentioned previously, the primary ERP of interest is the error-related negativity (ERN), a negative-polarity electrophysiological signal that occurs about 80-100 ms after responding incorrectly (Gehring et al., 1993). The ERN has been shown to be enhanced in OCD patients compared to controls. An additional ERP of interest is the correct-response negativity (CRN), which is a negative-polarity electrophysiological signal that occurs about 80-100 ms after a correct response (Ford, 1999; Vidal et al., 2003; Vidal et al., 2000). The CRN shows an association with obsessive-compulsive symptoms in some studies (Hajcak & Simons, 2002). The ERN was operationally defined as the most negative peak occurring between 0 and 150 ms after an incorrect response during the flanker task or after a suboptimal response during the probabilistic learning task. The CRN was operationally defined as the most negative peak occurring between 0 and 150 ms after a correct response during the flanker task or after an optimal response during the probabilistic learning task. For both the ERN and CRN, amplitude was defined as the distance between the negative peak (0-150 ms post response) and the preceding positive peak in the window -100 to 0 ms before the negative peak (Endrass et al., 2008; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Kopp, Rist, & Mattler, 1996). Based on the same criteria used by Gründler et al. (2009), no ERP was based on fewer than 30 EEG epochs in all conditions.

The ERPs and behavioral measures were statistically analyzed using SPSS (Version 17.0) software. A repeated-measures ANOVA was used to compare the trough-to-peak ERN and CRN amplitudes for each task (flanker and probabilistic learning) using the between-subjects factors: group (OCD vs. control) and condition (easy vs. difficult) and the within-subjects factors: electrode (electrodes 6, 55, and 62) and response (correct or incorrect). The electrodes used for statistical analyses were chosen because they fall on midline sites that are of a-priori interest based on research showing that the ERN and CRN amplitudes are highest in the frontal-central midline sites (Holroyd & Coles, 2002). Additionally, these three electrodes were chosen because they represent frontal, central, and parietal locations on the scalp that correspond to the 10-20 electrode sites of FCz, CPz, and POz, respectively, which facilitates comparison with other studies (Luu & Ferree, 2005; see figure 2).

This study hypothesizes that there will be a significant main effect for group with the high OC group showing larger ERN and CRN amplitudes than the low OC group for the easy versions of both tasks. This study also predicts a significant main effect for condition; ERN and CRN amplitudes are expected to be attenuated during the difficult versions of flanker and probabilistic learning tasks. Additionally, an interaction between group and condition is predicted for both tasks. This study predicts that individuals with greater obsessive-compulsive symptoms will be affected by the uncertainty of the task to a greater extent than controls and are hypothesized to show significantly smaller ERN amplitudes when the task is difficult. For the within-subjects factor, electrode, the frontal and central electrodes are expected to show stronger effects than the parietal electrode. For the repeated-measures analyses, the Greenhouse–Geisser procedure was used to correct *p*-values when necessary (e.g. when degrees of freedom were greater than 1). Post-hoc comparisons will be used to parse the results of significant main effects or interactions and Bonferoni corrected *p*-values will be reported for post-hoc tests.

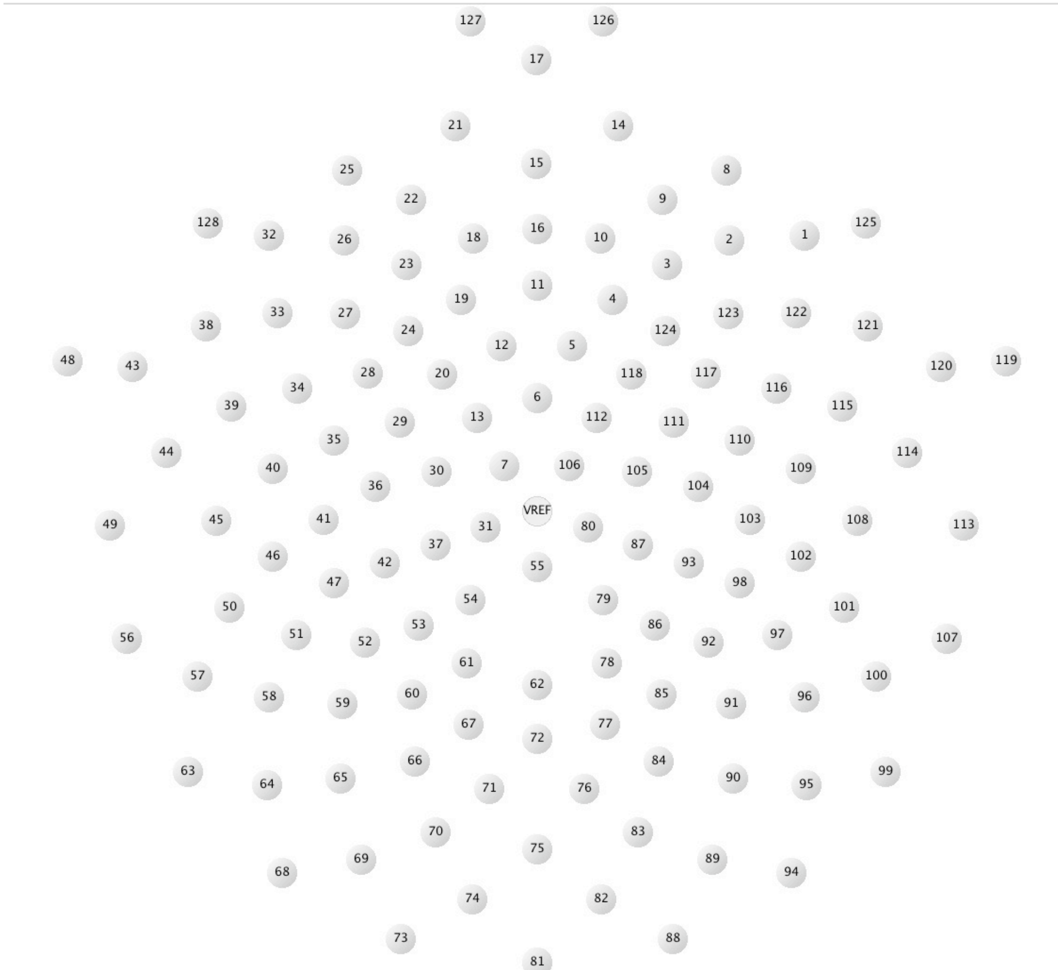

Figure 2: Electrode positions for the Geodesics Sensor Cap (Electrical Geodesics Inc., Eugene, OR). Note that EGI caps do not follow the standard 10-20 system of electrode placement. Electrodes tested for significance in this study included 6, 55, and 62, each representing a frontal, central, or parietal site on the scalp that corresponds to FCz, CPz, and POz, respectively (Luu & Ferree, 2005).

3. Results:

3.1 Behavioral data

Based on subjective ratings of task difficulty, the basic experimental design was effective in manipulating task difficulty for both the flanker and the probabilistic learning tasks. As mentioned previously, the flanker task with degraded stimuli and a shorter response window was rated by participants as significantly more difficult than the original flanker task ($t(116) = 9.13$, $p < .001$, see table 2 for mean difficulty ratings). Participants rated the version of the probabilistic learning task with the more explicit probabilities (100 vs. 0, 95 vs. 5, and 90 vs. 10 percent) as significantly less difficult than the original probabilistic learning task ($t(115) = -4.88$, $p < .001$, means reported in table 2). The high and low obsessive-compulsive groups did not differ in their subjective ratings of task uncertainty for the flanker task ($t(116) = .028$, $p = .98$, low M = 4.76, high M = 4.88) but the two groups did differ in their perception of task difficulty for the probabilistic learning task with the high obsessive-compulsive group rating the probabilistic learning task as more difficult than the low obsessive-compulsive group ($t(115) = -2.39$, $p = .018$, low OC M = 7.01, high OC M = 7.86). As expected, all participants perceived both versions of the probabilistic learning task as more difficult than the versions of the flanker task. Participants rated the easy version of the probabilistic learning task as more difficult than the easy version of the flanker task ($t(116) = 8.59$, $p < .001$, easy probabilistic learning M = 6.58, easy flanker M = 3.38) and they rated the difficult version of the probabilistic learning task as more difficult than the difficult version of the flanker task ($t(115) = 7.08$, $p < .001$, difficult probabilistic learning M = 8.29, difficult flanker M = 6.25).

The high and low obsessive-compulsive groups showed similar levels of accuracy during the flanker task ($t(116) = -1.37$, $p = .17$; see table 1 for accuracy means) and the probabilistic learning task ($t(116) = 1.36$, $p = .18$; see table 1 for accuracy means). The high and low obsessive-compulsive groups did not show differences in mean response times for either task (flanker: $t(116) = .87$, $p = .39$; probabilistic learning: $t(116) = .64$, p

= .52; see table 1 for mean response times by group). Participants were more accurate during the easy version of the flanker task than during the difficult version ($t(116)$ = 10.07, $p < .001$, see table 2 for accuracy means by task). There were no differences in accuracy for the easy and difficult versions of the probabilistic learning task ($t(116)$ = 1.26, $p = .21$, see table 2 for accuracy means by task). The number of trials used to derive the ERPs associated with incorrect responses was smaller than the number of trials used to derive the ERPs associated with correct responses, which is expected since there are many more correct trials than incorrect trials. Although this imbalance may result in a decrease in the signal-to-noise ratio for the incorrect-response ERPs, as mentioned earlier, the accuracy levels were not significantly different between the high and low OC groups. Therefore, differences in these two groups cannot be accounted for by disparate accuracy levels between the groups. However, there was a significant difference in accuracy between the easy and difficult versions of the flanker task (but not the probabilistic learning task). This suggests that fewer errors were made during the easy version of the flanker task; therefore, there is less data for deriving ERPs in this condition, which could potentially introduce extra noise into the results.

3.2 ERP results for flanker task

The flanker and probabilistic learning tasks were statistically analyzed using repeated-measures ANOVA. The trough-to-peak ERN and CRN amplitudes for each task were compared using the between-subjects factors: group (low and high obsessive-compulsive) and condition (easy vs. difficult) and the within-subjects factors: electrode (electrodes 6, 55, and 62) and response (correct or incorrect). For the flanker task, a repeated-measures ANOVA revealed a significant main effect for response ($F(1, 113) = 12.96, p < .001$). A main effect for response suggests that the ERN amplitudes (mean = 3.27) were significantly larger than the CRN amplitudes (mean = 2.74), which has also been demonstrated in previous studies examining the CRN. The was no significant main effect for electrode ($F(1.76, 198.63) = 1.14, p = .32$) which suggests that these three electrodes did not significantly differ from each other in terms of ERN or CRN amplitudes. Additionally, significant main effects were found for Group ($F(1, 114) = 4.77, p = .03$) and Condition ($F(1, 114) = 6.88, p = .01$) but no significance was found for the interaction Group x Condition ($F(1, 114) = .01, p = .94$). No significant differences were found between males and females in terms of ERN or CRN amplitudes during the flanker task (ERN: $F(1, 110) = 1.9, p = .67$, males M = 2.81, females M = 2.97; CRN: $F(1, 109) = .86, p = .36$, males M = 1.92, females M = 2.14).

The difference in the ERN and CRN waveforms between the high and low obsessive-compulsive groups and between the easy and difficult conditions of the flanker task is illustrated in figures 3a-3d. The high OC group was predicted to show significantly larger ERN and CRN amplitudes than the low OC group, which would be consistent with research that shows a relationship between OCD and these ERPs. The current study shows that the high OC group produced larger ERN amplitudes than the low group; however, a significant difference between the high and low OC groups was only found during the easy version of the flanker task (ERN: $t(34) = -2.64, p = .01$, high OC mean = 4.09, low OC mean = 3.22). The difference in CRN amplitudes between the high and low OC groups approached significance during the easy flanker task ($t(34)$ = -

1.89, p = .06, high OC mean =3.20, low OC mean = 2.35). There was no significant difference between the high and low OC groups for ERN or CRN amplitudes during the difficult flanker task (ERN: $t(57)$ = -1.05, p = .30, high OC mean = 2.80, low OC mean = 2.73; CRN: $t(57)$ = -1.39, p = .14, high OC mean = 2.57, low OC mean = 2.66).

The ERN and CRN amplitudes produced during the easy flanker task were predicted to show greater negativity than those produced during the difficult version of the flanker task, which would be consistent with the work of Pailing and Segalowitz (2004) who found that the increasing uncertainty in a task attenuates ERN amplitudes. The current study found a difference between ERN and CRN amplitudes based on task difficulty; however, this task-related amplitude difference is only significant in the high OC group (ERN: $t(34)$ = -2.88, p = .01, easy flanker mean = 4.34, difficult flanker mean = 3.01; CRN: $t(34)$ = -2.36, p = .02, easy flanker mean = 3.56, difficult flanker mean = 2.98). The ERN and CRN amplitudes for the low OC group did not significantly differ between the easy and difficult versions of the flanker task (ERN: $t(57)$ = -1.10, p = .32, mean for easy flanker = 2.90, mean for difficult flanker = 2.23; CRN: $t(57)$ = .90, p = .40, mean for easy flanker = 2.51, mean for difficult flanker = 2.45). Thus, it appears that only the high OC group in this study shows attenuation of ERN amplitudes with increasing task difficulty. The relationship between obsessive-compulsive symptoms and ERN and CRN amplitudes during the two versions of the flanker task is further illustrated in figures 4 and 5.

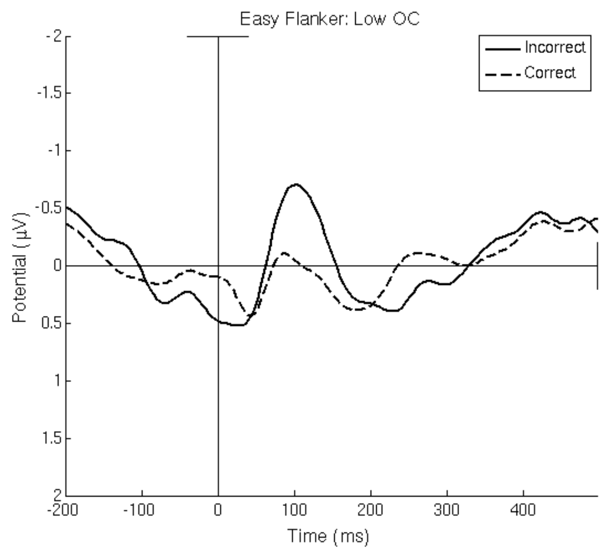

Figure 3a: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the low OC group during the easy flanker task.

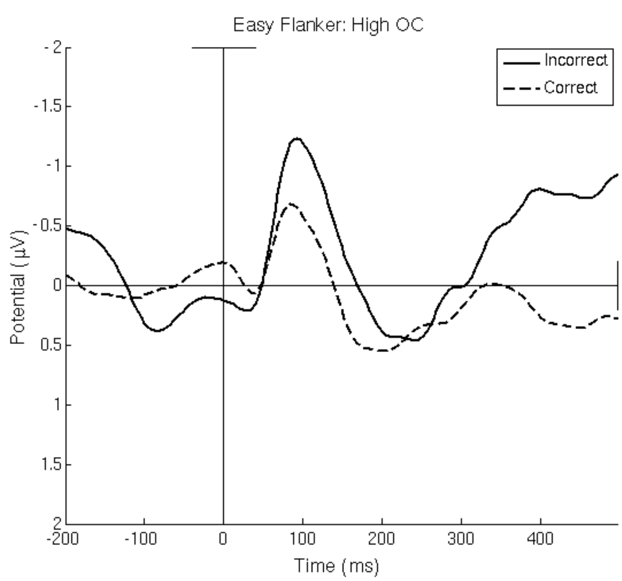

Figure 3b: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the high OC group during the easy flanker task.

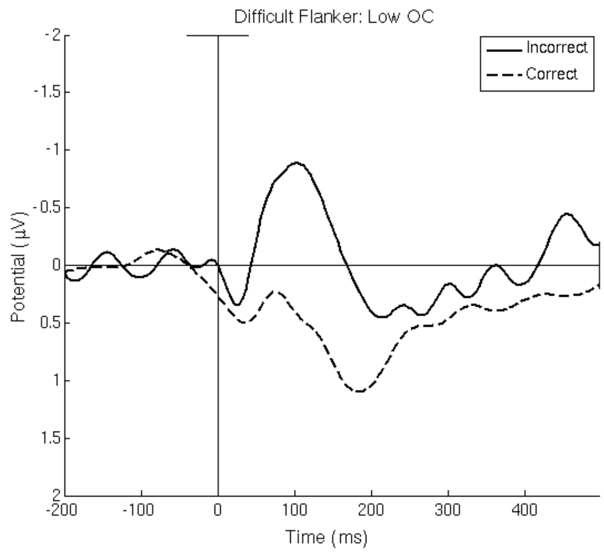

Figure 3c: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the low OC group during the difficult flanker task.

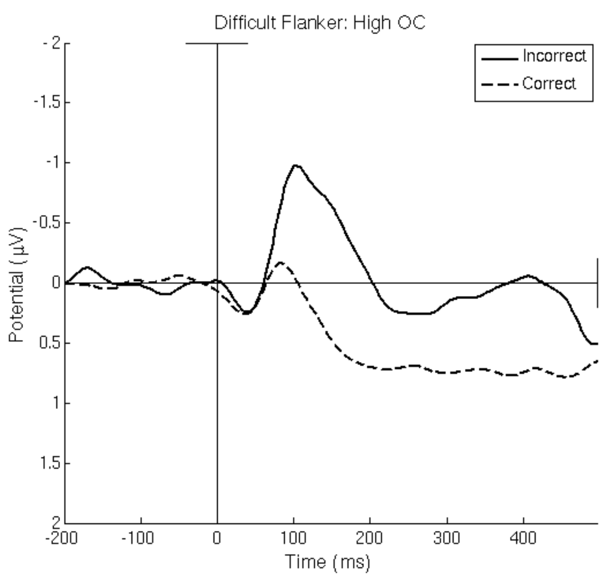

Figure 3d: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the high OC group during the difficult flanker task.

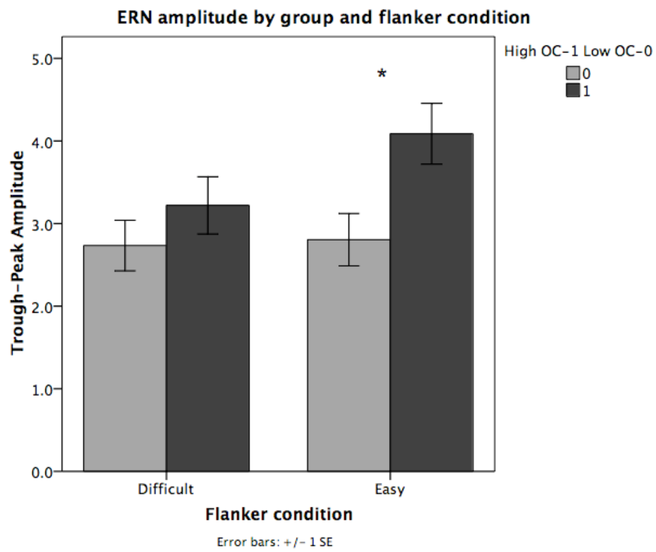

Figure 4: ERN amplitudes for incorrect trials by group and flanker condition. Significant mean differences are marked with an asterisk.

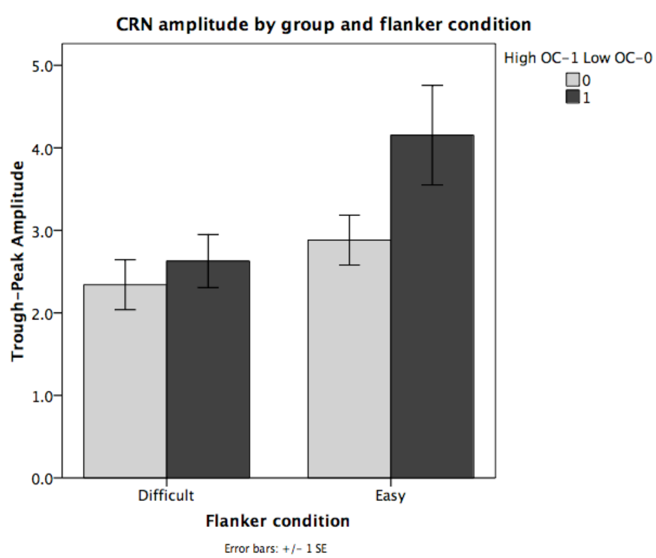

Figure 5: CRN amplitudes for correct trials by group and flanker condition.

3.3 *ERP results for probabilistic learning task*

For the probabilistic learning task, a repeated-measures ANOVA revealed a significant main effect for Response (correct vs. incorrect; $F(1, 114) = 12.43$, $p = .001$, CRN mean = 2.48, ERN mean = 2.83) and a significant main effect for Electrode ($F(1.58, 180.50) = 15.89$, $p < .001$). Pair wise comparisons using Bonferroni correction show that electrode 6 is significantly greater in amplitude than electrode 55 (electrode 6 M = 3.15, electrode 55 M = 2.54) and electrode 6 is significantly different from electrode 62 (electrode 62 M = 2.72). However, the mean amplitudes for electrodes 55 and 62 were not significantly different from one another. A significant main effect for response suggests that the ERN amplitudes are significantly different than the CRN amplitudes. The ERN amplitudes (mean = 2.4) were larger than the CRN amplitudes (mean = 2.0), which is consistent with prior research showing that CRN waveforms are typically smaller in amplitude. There were no significant main effects for Condition ($F(1, 114) = .36$, $p = .55$), Group ($F(1, 114) = .29$, $p = .59$), or the interaction between Group and Condition ($F(1, 114) = .64$, $p = .43$). No significant differences were found between males and females in terms of ERN amplitudes during the probabilistic learning task ($F(1, 110) = 2.32$, $p = .13$, males M = 3.06, females M = 2.50) but males showed significantly larger CRN amplitudes than females during this task ($F(1, 110) = 6.86$, $p = .01$, males M = 2.90, females M = 2.13).

Figures 6a-6b show the difference in the ERN and CRN waveforms between the high and low obsessive-compulsive groups and between the easy and difficult conditions of the probabilistic learning task. There were no significant differences in ERN amplitudes between the high and low obsessive-compulsive groups (*F*(1, 114) = .29, *p* = .59; high OC M = 2.98, low OC M = 2.41), which is consistent with the findings of Nieuwenhuis et al. (2005) who also found no ERN amplitude differences between OCD patients and controls using a probabilistic learning task. Additionally, there was no significant difference in CRN amplitude between the high and low obsessive-compulsive groups (*F*(1, 114) = .33, *p* = .57, high OC mean = 2.25, low OC mean = 2.34). A lack of a significant main effect for condition (easy vs. difficult probabilistic learning task) suggests that manipulating task difficulty in a probabilistic learning task has no effect on ERN or CRN amplitudes, contrary to this study's hypotheses. Figures 7 and 8 further show the lack of a significant relationship between obsessive-compulsive symptoms and ERN or CRN amplitudes during the easy and difficult versions of the probabilistic learning task. Although previous research by Hajcak and Simons (2002) reported enhanced negativity following both correct and incorrect trials, the present study did not find differences between the high and low obsessive-compulsive groups in terms of CRN amplitudes during the probabilistic learning tasks.

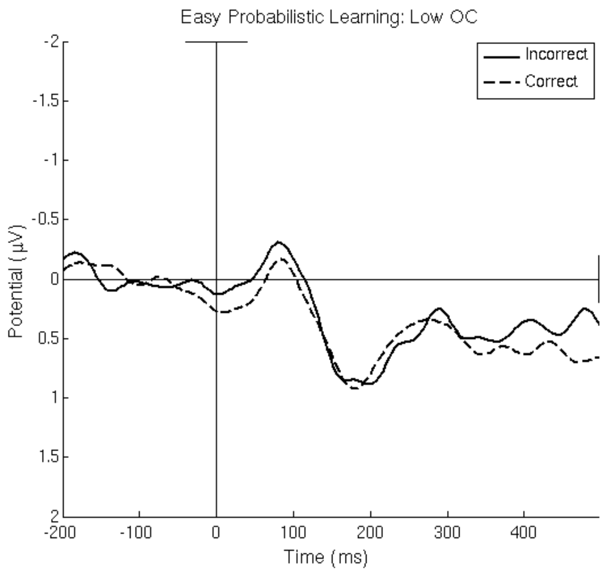

Figure 6a: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the low OC group during the easy probabilistic learning task.

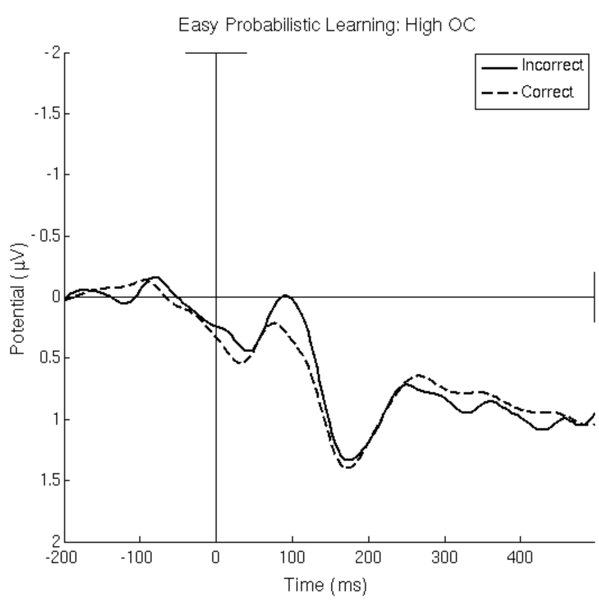

Figure 6b: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the high OC group during the easy probabilistic learning task.

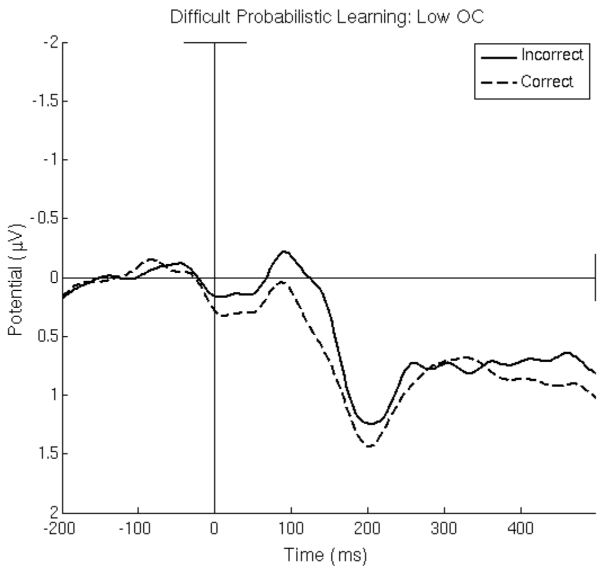

Figure 6c: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the low OC group during the difficult probabilistic learning task.

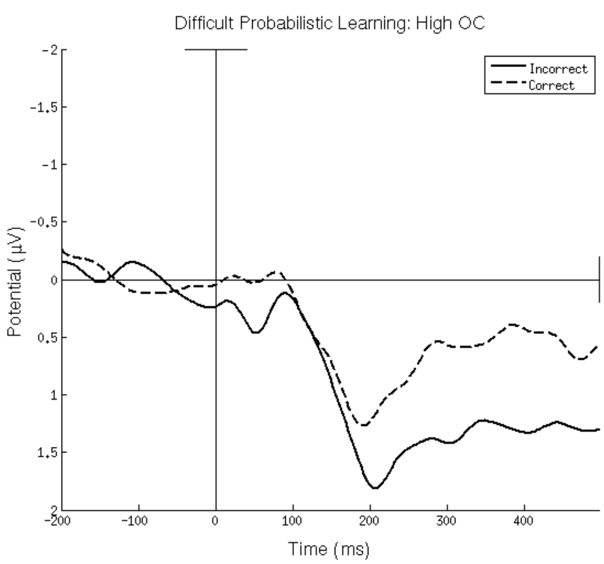

Figure 6d: Stimulus-locked grand-averaged waveforms for correct and incorrect trials in the high OC group during the difficult probabilistic learning task.

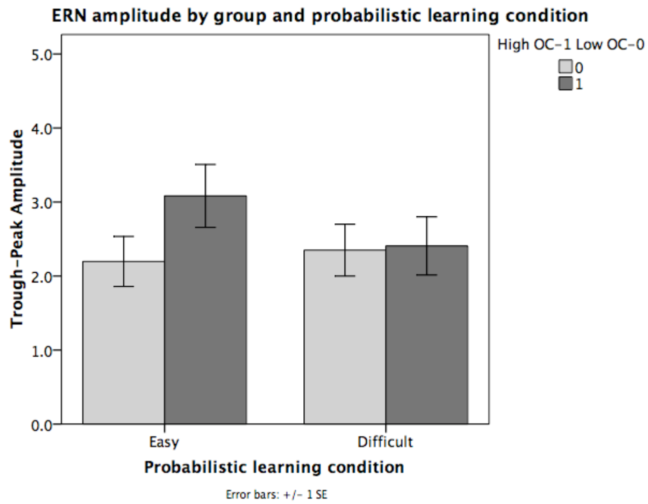

Figure 7: ERN amplitudes for incorrect trials by group and probabilistic learning condition.

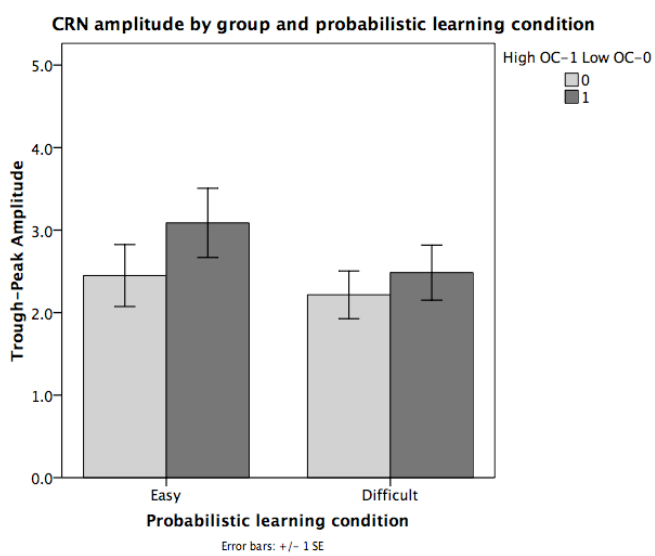

Figure 8: CRN amplitudes for correct trials by group and probabilistic learning condition.

4. Discussion:

The first aim of the present study was to investigate the effect of task difficulty on ERN and CRN amplitudes. This study hypothesized that the uncertainty of the task would moderate the amplitudes of the ERN and CRN in both the flanker and probabilistic learning tasks. Manipulating task difficulty to create easy and difficult versions of the flanker and probabilistic learning tasks allowed us to test this hypothesis. As expected, participants rated the difficult version of the flanker task as more difficult than the original version and the easy version of the probabilistic learning task as easier than the original version, which suggests that the experimental manipulation of task difficulty was successful. However, modification of task difficulty only had an effect on flanker ERN and CRN amplitudes but not probabilistic learning ERN or CRN amplitudes. Increasing the difficulty of the flanker task resulted in smaller ERN and CRN amplitudes, which is consistent with research by Pailing and Segalowitz (2004) where increasing uncertainty was shown to attenuate ERN amplitudes; however, this effect was only found in the high OC group during the flanker task. The low OC group did not show attenuation of ERN or CRN amplitudes during the flanker task. Contrary to this study's prediction, manipulating task difficulty did not significantly change ERN or CRN amplitudes during the probabilistic learning task. This finding cannot be explained by a failure of the experimental design to alter the difficulty of the task since participants' subjective ratings confirmed the difficulty levels of the easy and difficult versions of the probabilistic learning task.

The second aim of this study was to investigate the effect of task difficulty in individuals with high or low obsessive-compulsive traits. In this study, the high obsessive-compulsive group showed larger ERN amplitudes following incorrect responses than the low obsessive-compulsive group, which is consistent with previous research (Gehring et al., 2000; Johannes et al., 2001; Ruchsow et al., 2005; Endrass et al., 2008; Hajcak & Simons, 2002; Santesso et al., 2006). However, the difference between the high and low OC groups was only found during the easy flanker task. Based on research by Hajcak and Simons (2002) and Endrass et al. (2008) showing enhanced negativity following both correct and incorrect trials in high obsessive-compulsive participants, the present study investigated ERP amplitudes for correct trials (CRN). Enhanced negativity following correct and incorrect trials suggests that those with OCD may show excessive performance monitoring regardless if an error is made or not (Endrass et al., 2008; Hajcak & Simons, 2002). This study was able to show a negative ERP for correct trials in both the high and low obsessive-compulsive individuals. Comparison of the high and low obsessive-compulsive groups in the present study did not show significant CRN amplitude differences in either the flanker or the probabilistic learning tasks; however, there was a nonsignificant trend towards larger CRN amplitudes in the high OC group during the easy flanker task.

This study predicted that individuals with obsessive-compulsive symptoms would show smaller ERN and CRN amplitudes when the task is difficult compared to when the task is easy in both the flanker and probabilistic learning paradigms. This hypothesis is based on previous research showing that participants with obsessive-compulsive traits show smaller ERN amplitudes during a probabilistic learning task (Gründler et al., 2009). Additionally, based on research showing that those with OCD are less tolerant of uncertainty (Tolin et al., 2003; Holaway et al., 2006), it was predicted that the difficult nature of the probabilistic learning task might have a stronger effect on those with obsessive-compulsive symptoms than controls. Those with OCD symptoms might have an impaired ability to respond adaptively when the correct response is ambiguous.

The results of this study provide evidence that individuals with obsessive-compulsive tendencies show smaller ERN and CRN amplitudes when the task is difficult compared to when the task is easy; however, this occurred only during the flanker task and not during the probabilistic learning task. There was no significant difference between the ERN and CRN amplitudes in the easy and difficult probabilistic learning tasks for the high obsessive-compulsive group. These results provide novel evidence that the CRN is also sensitive to task difficulty in response conflict but not reinforcement learning paradigms. The hyperactive performance monitoring theory postulates that those with OCD have an overactive error monitoring circuit regardless of the task. However, this study shows that during the flanker task, individuals with high obsessive-compulsive traits show smaller ERN and CRN amplitudes when the task becomes difficult. The attenuation is great enough that there is no longer a difference between the high and low OC groups in terms of ERN or CRN amplitudes during the difficult flanker task. Based on the results of this study, obsessive-compulsive individuals appear to have an overly active performance monitoring system when there is a clearly correct response but no hyperactivation when the correct response is ambiguous. The results of this study also suggest that the overactive error-monitoring activity usually associated with OCD depends on the difficulty and type of task performed, with greater task difficulty attenuating ERN and CRN amplitudes in response conflict but not reinforcement learning tasks.

It is unclear why increasing task difficulty would attenuate ERN and CRN amplitudes in a flanker task but not in a probabilistic learning task. As was mentioned previously, the probabilistic learning task is inherently difficult and participants are often unsure of the correct response. Since uncertainty in a task can attenuate ERN amplitudes, this study predicted that the smaller ERN amplitudes found during probabilistic learning are simply due to the difficult nature of the task. This was not supported by the results of this study. Making the probabilistic learning task less difficult had no effect on ERN or CRN amplitudes. One possible explanation for the lack of difference between ERN and CRN amplitudes in the easy and difficult versions of the probabilistic learning task is that both tasks are still too difficult to reliably elicit an ERN or CRN. Although the easy probabilistic learning task was rated as easier than the difficult probabilistic learning task, both versions were still rated more difficult than the flanker tasks. In other words, participants rated the easy probabilistic learning task as significantly more difficult than both the easy and difficult flanker tasks. Perhaps the easier version of the probabilistic learning task is still difficult enough to significantly attenuate ERN and CRN amplitudes, which would explain why there is no amplitude difference between the easy and difficult probabilistic learning tasks.

In this respect, task-related ERN amplitudes could be viewed as an inverted u-shaped curve where a moderate amount of uncertainty produces the typical ERN amplitude differences between easy and difficult tasks but once the uncertainty of the task exceeds some threshold, the ERN amplitude decreases. Intuitively, it would make sense that as a task becomes too difficult, the performance monitoring system may be incapable of producing an ERN because the participant is no longer sure of what constitutes a correct or incorrect response. The inverted u-shaped model of ERN amplitudes would be consistent with studies that find that increasing the uncertainty in a task attenuates ERN amplitudes (Pailing & Segalowitz, 2004). It is less clear what the threshold for uncertainty would need to be before ERN amplitudes began to decrease. Based on the results of this study, one could argue that the easy version of the flanker task did not exceed the uncertainty threshold but the difficult flanker task did exceed this threshold and thus, a clear ERN difference can be seen between the easy and difficult versions of the task. Conversely, the easy and difficult versions of the probabilistic learning task may both exceed the threshold of uncertainty, which is why the ERNs are attenuated and show no differences. This same logic may apply to the CRN as well; however, as mentioned earlier, the CRN is not as reliably found as the ERN for reasons that are currently unknown.

Gründler et al. (2009) offer an additional explanation for the divergence between the flanker and probabilistic learning tasks in terms of ERN amplitudes. The authors suggest that the ERN elicited during motor errors of commission, as found in a flanker task, and the ERN elicited in a reinforcement learning paradigm like the probabilistic learning task may result from different underlying neural systems. They proposed that the ERN found during motor errors of commission and the ERN found during reinforcement learning both likely originate from the anterior cingulate cortex (ACC) but they suggest that motor errors of commission originate in the rostral area of the ACC while reinforcement learning ERNs may manifest in the dorsal ACC. Gründler et al. (2009) support this by citing data from fMRI studies showing that OCD patients differ in terms of activation of the ACC, such that error-related hemodynamic responses (those found during motor error of commissions) are associated with the rostral ACC and conflict-related hemodynamic responses (those found during probabilistic learning) are associated with the caudal ACC (Fitzgerald et al., 2005; Maltby et al., 2005; Ursu et al., 2003). Gründler et al. (2009) suggest that the existence of different yet overlapping neural mechanisms responsible for distinct types of performance monitoring may explain the inconsistent results found with the probabilistic learning task.

The current study's finding that the flanker and probabilistic learning tasks are not similarly affected by manipulation of task difficulty may be consistent with the idea that these two tasks elicit ERNs that originate from different neural mechanisms. Different neural mechanisms imply that the ERNs produced in these two tasks may also differ in their functional significance. In fact, the functional significance of the ERN is still speculated. Early research on performance monitoring proposed that the ERN reflects error detection, or more specifically, the mismatch between the response required and the actual response made (Falkenstein et al., 2000; Gehring et al., 1993). Others have suggested that the ERN is the result of response conflict, such that distinct pathways that lead to a correct or an incorrect response are simultaneously activated leading to conflicting response representations (Botvinick, Braver, Barch, Carter, & Cohen, 2001). An additional theory by Holroyd and Coles (2002) postulates that errors give rise to negative reinforcement learning signals, which are use to modify performance. In other words, "worse than expected" outcomes lead to an error signal that trains the motor system by way of reinforcement learning principles (Holroyd & Coles, 2002). It is possible that the ERNs associated with the flanker and probabilistic learning tasks also differ in their functional significance.

The divergence between the flanker and probabilistic learning tasks found in the present study may be due to the existence of different yet overlapping neural mechanisms where each system produces distinct ERNs with different functional significance. Perhaps the error detection and response conflict theories are more consistent with the ERN found during motor errors of commission (i.e. errors elicited by a flanker task), while the reinforcement learning theory may be more consistent with the ERN elicited by a probabilistic learning task. However, additional research is needed to support or refute this theory and to determine if a similar theory applies to the CRN as well. As mentioned previously, it is also possible that both the easy and difficult versions of the probabilistic learning task are too difficult to reliably elicit a difference in ERN or CRN amplitudes. However, it is difficult to imagine how the probabilistic learning task can be made easier while still retaining the probabilistic nature of the task. The easy version of this task used in the present study had probabilities of 90, 95, and 100 percent (compared to the original probabilities of 60, 70, and 80 percent). If the probabilities are much closer to 100 percent, then the correct choice will always be known and the task will no longer be probabilistic. It may also be the case that there exists some other, alternative reason for the divergence between the flanker and probabilistic learning tasks in terms of ERN and CRN amplitudes in response to manipulation of task difficulty. The results of this study suggest that the smaller ERN amplitudes found during probabilistic learning are not likely due the difficulty of the task but to some other, presently unidentified cause.

A possible limitation to the present study is the use of college students with obsessive-compulsive traits rather than OCD patients; however, other researchers have reliably found group differences in ERN amplitudes while using nonclinical student populations (Gründler et al., 2009; Hajcak & Simons, 2002). Additionally, besides being a convenient population, the sample used in this study is fairly homogenous in terms of age and education level. Furthermore, although an OCI-R score of 21 or greater was used as the cutoff to create the high OC group, the mean OCI-R score for the high group was closer to 30 with a substantial range in high OC scores (21-51). Our mean of 30.51 is comparable to the mean OCI-R score of 27.7 reported by Endrass et al. (2008) using a sample of clinical patients with OCD. However, replication of the results of the present study in a clinical sample will be necessary to generalize these findings.

5. Conclusion:

Previous research has found that individuals with OC tendencies show smaller ERN amplitudes during a probabilistic learning task. The current study hypothesized that these results may be due to the difficult nature of the task. This study manipulated the difficulty of the probabilistic learning task and the flanker task to test the hypothesis that uncertainty regarding the correct response may moderate ERN and CRN amplitudes in these tasks. The results of this study show that the level of difficulty during the probabilistic learning task had no effect on ERN or CRN amplitudes, suggesting that the smaller ERN amplitudes found during probabilistic learning are not due to the difficult nature of the task. In addition, individuals with OC traits were predicted to show smaller ERN and CRN amplitudes when the task was difficult. Individuals with high OC traits show attenuated ERN and CRN amplitudes during the difficult flanker task. The results of this study suggest that task difficulty may moderate performance monitoring during motor errors of commission but not during reinforcement learning paradigms. And there is evidence that individuals with obsessive-compulsive traits may be affected by uncertainty in a task to a greater extent than controls. Additional research is needed to replicate these results.

6. Bibliography:

Adler, C. M., McDonough-Ryan, P., Sax, K. W., Holland, S. K., Arndt, S., & Strakowski, S. M. (2000). fMRI of neuronal activation with symptom provocation in unmedicated patients with obsessive compulsive disorder. *Journal of Psychiatric Research, 34*, 317–324.

American Psychiatric Association. (2000). Diagnostic and statistical manual of mental disorders (DSM-IV) (4th ed. (text revision)). Washington, DC: American Psychiatric Association.

Beck, A. T. & Steer, R. A. (1987). Manual for the Beck Depression Inventory. New York, NY: Psychological Corporation.

Breiter, H. C. & Rauch, S. L. (1996). Functional MRI and the study of OCD: From symptom provocation to cognitive-behavioral probes of cortico-striatal systems and the amygdala. *Neuroimage*, *4*, S127–138.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652.

Cottraux, J., Gerard, D., Cinotti, L., Froment, J. C., Deiber, M. P., Le Bars, D., … Mauguire, F. (1996). A controlled positron emission tomography study of obsessive and neutral auditory stimulation in obsessive-compulsive disorder with checking rituals. *Psychiatry Research, 60*, 101-112.

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., von Cramon, D. Y., & Engel, A. K. (2005). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. *Journal of Neuroscience*, *25*(50), 11730–11737.

Endrass, T., Klawohn, J., Schuster, F., & Kathmann, N. (2008). Overactive performance monitoring in obsessive–compulsive disorder: ERP evidence from correct and erroneous reactions. *Neuropsychologia*, *46*, 1877–1887.

Eriksen, B. & Eriksen, C. B. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception and Psychophysics*, *16*, 143–169.

Falkenstein, M., Hoormann, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: A tutorial. *Biological Psychology, 51*, 87–107.

Fitzgerald, K. D., Welsh, R. C., Gehring, W. J., Abelson, J. L., Himle, J. A., Liberzon, I., & Taylor, S. F. (2005). Error-related hyperactivity of the anterior cingulate cortex in obsessive–compulsive disorder. *Biological Psychiatry*, *57*, 287–294.

Foa, E. B., Huppert, J. D., Leiberg, S., Langner, R., Kichic, R., Hajcak, G., & Salkovskis, P. M. (2002). The Obsessive–Compulsive Inventory: Development and Validation of a Short Version. *Psychological Assessment*, *14*, 485–496.

Ford, J. M. (1999). Schizophrenia: The broken P300 and beyond. *Psychophysiology, 36*, 667–682.

Frank, M. J., Woroch, B. S., & Curran, T. (2005). Error-related negativity predicts reinforcement learning and conflict biases. *Neuron, 47*, 495–501.

Fullana, M. A., Tortella-Feliu, M., Caseras, X., Andion, O., Torrubia, R., & Mataix-Cols, D. (2005). Psychometric properties of the Spanish version of the Obsessive–Compulsive Inventory—Revised in a non-clinical sample. *Journal of Anxiety Disorders*, *19*(8), 893–903.

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4*, 385-390.

Gehring,W. J., Himle, J., & Nisenson, L. G. (2000). Action-monitoring dysfunction in obsessive–compulsive disorder. *Psychological Science, 11*, 1–6.

Gründler, T. O. J., Cavanagh, J. F., Figueroa, C. M., Frank, M. J., & Allen, J. J. B. (2009). Task-related dissociation in ERN amplitude as a function of obsessive-compulsive symptoms. *Neuropsychologia, 47*, 1978-1987.

Hajcak, G., Huppert, J. D., Simons, R. F., & Foa, E. B. (2004). Psychometric properties of the OCI-R in a college sample. *Behavior Research and Therapy*, *42*, 115-123.

Hajcak, G. & Simons, R. F. (2002). Error-related brain activity in obsessive–compulsive undergraduates. *Psychiatry Research*, *110*, 63–72.

Holaway, R. M., Heimberg, R. G., & Coles, M. E. (2006). A comparison of intolerance of uncertainty in analogue obsessive-compulsive disorder and generalized anxiety disorder. *Journal of Anxiety Disorders, 20*, 158-174.

Holroyd, C. B. & Coles, M. G. H. (2002). The Neural Basis of Human Error Processing: Reinforcement Learning, Dopamine, and the Error-Related Negativity. *Psychological Review, 109,* 679-709.

Huppert, J. D., Walther, M. R., Hajcak, G., Yadin, E., Foa, E. B., Simpson, H. B., & Liebowitz, M. R. (2007). The OCI-R: Validation of the subscales in a clinical sample. *Journal of Anxiety Disorders*, *21*, 394–406.

Huyser, C., Veltman, D.J., de Haan, E., & Boer, F. (2009). Pediatric obsessive–compulsive disorder, a neurodevelopmental disorder? Evidence from neuroimaging. *Neuroscience & Biobehavioral Reviews, 33*, 818-830.

Johannes, S., Wieringa, B. M., Nager, W., Rada, D., Dengler, R., Emrich, H. M., … Dietrich, D. E. (2001). Discrepant target detection and action monitoring in obsessive–compulsive disorder. *Psychiatry Research*, *108*, 101–110.

Kopp, B., Rist, F., & Mattler, U. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology, 33*, 282-294.

Luu, P. & Ferree, T. (2005). Determination of the HydroCel Geodesic Sensor Nets' average electrode positions and their 10 – 10 international equivalents (technical report, Electrical Geodesics, Inc). Retrieved from the Electrical Geodesics, Inc website: ftp://ftp.egi.com/pub/documentation/technotes/ElectrodePositions.pdf

Maltby, N., Tolin, D. F., Worhunsky, P., O'Keefe, T. M., & Kiehl, K. A. (2005). Dysfunctional action monitoring hyperactivates frontal-striatal circuits in obsessive–compulsive disorder: An event-related fMRI study. *Neuroimage*, *24*, 495-503.

Mataix-Cols, D., Wooderson, S., Lawrence, N., Brammer, M. J., Speckens, A., & Phillips, M. L. (2004). Distinct neural correlates of washing, checking, and hoarding symptom dimensions in obsessive-compulsive disorder. *Archives of General Psychiatry, 61*, 564-576.

McGuire, P. K., Bench, C. J., Frith, C. D., Marks, I. M., Frackowiak, R. S., & Dolan, R. J. (1994). Functional anatomy of obsessive- compulsive phenomena. *The British Journal of Psychiatry, 164*, 459–468.

Menzies, L., Chamberlain, S. R., Laird, A. R., Thelen, S. M., Sahakian, B. J., & Bullmore, E. T. (2008). Integrating evidence from neuroimaging and neuropsychological studies of obsessive-compulsive disorder: The orbitofronto-striatal model revisited. *Neuroscience & Biobehavioral Reviews, 32*, 525-549.

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and Validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy 28*, 487-495.

Nieuwenhuis, S., Nielen, M. M., Mol, N., Hajcak, G., & Veltman, D. J. (2005). Performance monitoring in obsessive–compulsive disorder. *Psychiatry Research*, *134*, 111–122.

Pailing, P. E. & Segalowitz, S. J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and Cognition*, *56*, 215–233.

Pitman, R. K. (1987). A cybernetic model of obsessive–compulsive psychopathology. *Comprehensive Psychiatry, 28*, 334–343.

Phillips, M. L., Marks, I. M., Senior, C., Lythgoe, D., O'Dwyer, A. M., Meehan, O., … McGuire, P.K. (2000). A differential neural response in obsessive-compulsive disorder patients with washing compared with checking symptoms to disgust. *Psychological Medicine, 30*, 1037-1050.

Rauch, S. L., Jenike, M. A., Alpert, N. M., Baer, L., Breiter, H. C., Savage, C. R., & Fischman, A. J. (1994). Regional cerebral blood flow measured during symptom provocation in obsessive-compulsive disorder using oxygen 15-labeled carbon dioxide and positron emission tomography. *Archives of General Psychiatry, 51*, 62–70.

Rotge, J. Y., Guehl, D., Dilharreguy, B., Cuny, E., Tignol, J., Bioulac, B., … Aouizerate, B. (2008). Provocation of obsessive--compulsive symptoms: a quantitative voxel-based meta-analysis of functional neuroimaging studies. *Journal of Psychiatry & Neuroscience, 33*, 405-412.

Ruchsow, M., Gron, G., Reuter, K., Spitzer, M., Hermle, L., & Kiefer, M. (2005). Error-related brain activity in patients with obsessive–compulsive disorder and in healthy controls. *Journal of Psychophysiology*, *19*, 298–304.

Tolin, D. F., Abramowitz, J. S., Brigidi, B. D. & Foa, E. B. (2003). Intolerance of uncertainty in obsessive-compulsive disorder. *Journal of Anxiety Disorders, 17*, 233-242.

Santesso, D. L., Segalowitz, S. J., & Schmidt, L. A. (2006). Error-related electrocortical responses are enhanced in children with obsessive–compulsive behaviors. *Developmental Neuropsychology*, *29*, 431–445.

Schienle, A., Walter, B., Schaefer, A., Stark, R. & Vaitl, D. (2005). Neural responses of OCD patients towards disorder-relevant, generally disgust-inducing and fear-inducing pictures. *International Journal of Psychophysiology*, *57*, 69-77.

Shapira, N. A., Liu, Y., He, A. G., Bradley, M. M., Lessig, M. C., James, G. A.,…Goodman, W. K. (2003). Brain activation by disgust-inducing pictures in obsessive-compulsive disorder. *Biological Psychiatry, 54*, 751-756.

Simon, D., Kaufmann, C., Müsch, K., Kischkel, E., & Kathmann, N. (2010). Fronto-striato-limbic hyperactivation in obsessive-compulsive disorder during individually tailored symptom provocation. *Psychophysiology, 47*, 728-738.

Stemmer, B., Segalowitz, S. J., Witzke, W., & Schönle, P.W. (2003). Error detection in patients with lesions to the medial prefrontal cortex: An ERP study. *Neuropsychologia, 42*, 118–130.

Ullsperger, M. & von Cramon, D. Y. (2004). Neuroimaging of performance monitoring: Error detection and beyond. *Cortex*, *40*, 593–604.

Ursu, S., Stenger, V. A., Shear, M. K., Jones, M. R., & Carter, C. S. (2003). Overactive action monitoring in obsessive–compulsive disorder: Evidence from functional magnetic resonance imaging. *Psychological Science*, *14*, 347–353.

van den Heuvel, O. A., Veltman, D. J., Groenewegen, H. J., Cath, D. C., van Balkom, A. J., van Hartskamp, J., … van Dyck, R. (2005). Frontal-striatal dysfunction during planning in obsessive–compulsive disorder. *Archives of General Psychiatry*, *62*, 301–309.

van Veen, V. & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience*, *14*, 593–602.

Vidal, F., Burle, B., Bonnet, M., Grapperon, J., & Hasbroucq, T. (2003). Error negativity on correct trials: A reexamination of available data. *Biological Psychology, 64*, 265–282.

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the 'error negativity' specific to errors? *Biological Psychology, 51*, 109–128.

Watson, D., Clark, L. A., Weber, K., Assenheimer, J. S., Strauss, M. E., & McCormick, R. A. (1995a). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology, 104,* 3–14.

Watson, D., Clark, L. A., Weber, K., Assenheimer, J. S., Strauss, M. E., & McCormick, R. A. (1995b). Testing a tripartite model: II. Exploring the symptom structure of anxiety and depression in student, adult, and patient samples. *Journal of Abnormal Psychology, 104*, 15–25.

Whiteside, S. P., Port, J. D., & Abramowitz, J. S. (2004). A meta-analysis of functional neuroimaging in obsessive-compulsive disorder. *Psychiatry Research*, *132*, 69-79.