Parsing relationships between dimensions of anxiety and action monitoring brain potentials in female undergraduates

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Abstract

Anxiety is associated with enhanced action monitoring. Research to date, however, has employed extreme group designs that fail to address the full spectrum of anxiety, and in which overlapping and co-occurring symptoms obscure the exact nature of the relationships between anxiety and action monitoring. To address these limitations, relationships between distinct dimensions of anxiety and neural indicators of action monitoring were examined in a sample of female undergraduates. Results revealed that higher anxious apprehension (i.e., worry) was associated with enhanced early action monitoring activity, as indexed by the error-related negativity/correct-response negativity. Anxious arousal (i.e., somatic tension) on the other hand, was unrelated to measures of action monitoring. These findings suggest that the anxiety-action monitoring link holds along the continuum of severity and is specific to the worry component of anxiety.

Descriptors: Error-related negativity, Anxiety, Anxious apprehension, Anxious arousal

Anxiety is a common human experience that represents an adaptive response to threat (Marks & Nesse, 1994). Maladaptive anxiety, however, defines one of the most prevalent mental disorder categories (Kessler et al., 2005). Delineating factors that contribute to the development and maintenance of anxiety is therefore of great relevance to individuals at all levels of severity. A growing body of literature indicates that exaggerated action monitoring represents one important contributory factor (Olvet & Hajcak, 2008; Simons, 2010). Much of the research in this area, however, has examined extreme groups—either college students scoring high on anxiety or patients—that do not represent the full spectrum of anxiety symptoms. Moreover, such studies often include individuals characterized by a mixture of anxiety symptoms thus muddying the exact nature of the relationship between anxiety and action monitoring. As a first step towards addressing these limitations, the primary aim of the current study was to examine relationships between distinct dimensions of anxiety and neural correlates of action monitoring functions in an unselected sample of college students.

Drawing on early findings and conceptualizations (Barlow, 1991; Clark & Watson, 1991; York, Borkovec, Vasey, & Stern, 1987), Nitschke, Heller, Imig, McDonald, and Miller (2001) demonstrated that self-reported anxiety symptoms could be decomposed into two psychometrically distinct dimensions: anxious arousal and anxious apprehension. Anxious arousal is defined by somatic tension and physiological hyperarousal, whereas anxious apprehension is defined by worry. Establishing these psychometrically distinct dimensions was critical as such elemental psychological processes can be used to isolate specific relationships between different forms of anxiety and action monitoring, and they likely represent more viable targets for mapping onto biological mechanisms than highly heterogeneous and overlapping categorical disorders (Bearden & Freimer, 2006; Krueger, 1999; Watson, 2005).

Neuroimaging studies to date generally support the distinctions indicated by the questionnaire data. The aforementioned research group has shown that anxious arousal and anxious apprehension are characterized by unique patterns of regional brain activity. Specifically, anxious arousal has been associated with greater right-sided parietal activity, whereas anxious apprehension has been associated with greater left-sided frontal activity in emotion processing and resting state paradigms (Engels et al., 2007; Heller, Nitschke, Etienne, & Miller, 1997; Nitschke, Heller, Palmieri, & Miller, 1999). These findings dovetail with research showing that right-hemisphere parietal areas are involved in vigilance and arousal (Compton et al., 2003; Corbetta & Shulman, 2002) and left-frontal regions are involved in speech and language (Awh et al., 1996; Zatorre, Meyer, Gjedde, & Evans, 1996) and suggest that anxious arousal and anxious apprehension, respectively, enhance these functions.

Of specific relevance to the current investigation, anxiety has been associated with enhanced anterior cingulate cortex (ACC)—located in the medial frontal cortex—functioning in a variety of tasks (e.g., Fitzgerald et al., 2005). Several electrophysiological studies have found that anxiety is associated with enhancements of the error-related negativity (ERN), an event-related brain potential (ERP) component originating in the ACC (for reviews, see Olvet & Hajcak, 2008; Simons, 2010). The ERN

is a sharp negative deflection that shows its maximal amplitude at fronto-central recording sites approximately 50 ms after an erroneous response (Gehring, Goss, Coles, Meyer, & Donchin, 1993). Although its functional significance is the focus of continued debate, there is general agreement that the ERN reflects ACC-mediated action monitoring processes dedicated to optimizing performance (e.g., Botvinick, 2007). Based on conceptualizations that the ERN reflects error processing per se (Falkenstein, Hohnsbein, Hoorman, & Blanke, 1991; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001), several researchers have suggested that the enhanced ERN in anxious individuals reflects their sensitivity to and concern over mistakes (Hajcak, Moser, Yeung, & Simons, 2005; Weinberg, Olvet, & Hajcak, 2010).

The exact relationship between anxiety and the ERN is unclear, however. Some have suggested that enhanced ERN reflects a general underlying characteristic of all 'internalizing' problems—that is, all anxiety and depressive conditions (Olvet & Hajcak, 2008; Simons, 2010). Yet, most studies showing a relationship between anxiety and the ERN have examined a subset of specific conditions such as obsessive compulsive and generalized anxiety symptoms in isolation (Gehring, Himle, & Nisenson, 2000; Hajcak & Simons, 2002). Thus, the unique relationships between different forms of anxiety and action monitoring processes are not well understood. We know of only one study that has directly tested differential relationships between subtypes of anxiety and the ERN. Hajcak, McDonald, and Simons (2003) showed that worried but not spider-phobic undergraduates demonstrated enhanced ERN magnitude. It is possible then that enhanced ERN is specifically associated with anxious apprehension (see Simons, 2010; Weinberg et al., 2010 for a similar hypothesis).

The correct-response negativity (CRN; Vidal, Burle, Bonnet, Grapperon, & Hasbroucq, 2003; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000) and error positivity (Pe; Nieuwenhuis et al., 2001; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005) are two additional ACC-generated action monitoring brain potentials that may also be relevant to anxiety. The CRN is the ERN's correct response counterpart and peaks at approximately the same time (i.e., 50 ms after the response) and at similar scalp locations (i.e., fronto-central). Likewise, the CRN is believed to reflect similar action monitoring processes as the ERN, albeit on correct trials (Bartholow et al., 2005; Vidal et al., 2000, 2003). Several, but not all, investigations have shown enhanced CRN (as well as ERN) in anxious populations suggesting that anxiety is associated with a general increase in ACC-mediated action monitoring processes (Endrass, Klawohn, Schuster, & Kathmann, 2008; Endrass et al., 2010; Hajcak & Simons 2002; Hajcak et al., 2003). The Pe follows the ERN/CRN with a peak around 300 ms and shows its maximal amplitude at centro-parietal recording sites (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). Recent evidence further suggests that the Pe is comprised of two subcomponents—one fronto-central and one centro-parietal—that might reflect different processes (Arbel & Donchin, 2009; van Veen & Carter, 2002). The centro-parietally maximal Pe has received the most research attention (in general and in relation to individual differences) and is thought of as a P300-like wave that indexes error processing per se and specifically the awareness of and attention allocated to errors (Nieuwenhuis et al., 2001; Ridderinkhof, Ramautar, & Wijnen, 2009; Steinhauser & Yeung, 2010). We therefore focus on the centro-parietally maximal Pe in the present study. Fewer studies of anxiety include examination of the Pe, however. Moreover, two recent patient studies yielded

mixed findings (Endrass et al., 2008; Weinberg et al., 2010). Another study of undergraduates high in negative affect—a construct linked to anxiety and depression—showed reduced Pe amplitude suggestive of an impairment in error awareness (Hajcak, McDonald, & Simons, 2004).

In order to begin clarifying the relationships between different forms of anxiety and action monitoring processes, associations between psychometrically and theoretically distinct dimensions of anxiety and action monitoring ERPs were examined. Specifically, we examined relationships between anxious apprehension and anxious arousal and the ERN, CRN, and Pe in a sample of unselected female undergraduates representing a range of anxiety symptoms. This approach has already garnered support in that previous research has demonstrated unique associations between these dimensions and regional brain activity (Engels et al., 2010; Heller et al., 1997). Extending relationships between anxiety and action monitoring to individuals representing a range of more moderate levels of anxiety symptoms will help lend complimentary support to current conceptualizations that anxiety represents a dimension along a continuum from mild to extreme, with disordered patients falling at the high end of extreme (Brown & Barlow, 2009; Watson, 2005). In fact, work by Ruscio, Borkovec, and Ruscio (2001) showed that anxious apprehension—that is, worry—is dimensional in nature, with generalized anxiety disorder (GAD) representing the severe extreme. We selected only females for the current investigation because they are nearly twice as likely to suffer from anxiety-related problems (Kessler et al., 2005; Lewinsohn, Gotlib, Lewinsohn, Seeley, & Allen, 1998), thus making them a particularly important group to study.

Based on numerous findings in nonclinical (e.g., Hajcak et al., 2003) and clinical (e.g., Weinberg et al., 2010) samples, our strongest prediction was that anxious apprehension would be associated with enhanced ERN magnitude. Our next strongest hypothesis was that anxious apprehension would also be associated with enhanced CRN magnitude, given that several studies have demonstrated enhanced CRN in anxious subjects (Endrass et al., 2008, 2010; Hajcak & Simons, 2002; Hajcak et al., 2003). These hypotheses are further justified by theory and research in related areas suggesting that anxious apprehension is associated with enhanced frontal cortex function (e.g., Heller et al., 1997). Our hypotheses for anxious arousal and the Pe were more tentative. Although no studies to date have directly examined the relationship between anxious arousal and the ERN/CRN, Hajcak et al. (2003) found no relationship between spider fear and ERN/CRN. Insomuch as anxious arousal and fear share phenomenological features (e.g., the focus on immediate danger; Nitschke, Heller, & Miller, 2000), we cautiously hypothesized that anxious arousal would not be associated with ERN or CRN magnitude. Again, this hypothesis is further supported by theory and research suggesting that anxious arousal is not associated with enhanced frontal cortex function, but rather enhanced parietal cortex function (e.g., Nitschke et al., 1999). Finally, because previous studies have been mixed with regard to the relationship between anxiety and the Pe, our approach was exploratory.

Method

Participants

Seventy-one female undergraduates participated in the current study for course credit. No participants discontinued their

involvement once beginning the experiment. Four participants were excluded from analyses because of committing fewer than six errors per Olvet and Hajcak (2009). The final sample consisted of 67 participants (*M* age = 19.52, *SD* = 1.65).

Task

The primary task consisted of a letter version of the Eriksen Flankers task (Eriksen & Eriksen, 1974). Participants were instructed to respond to the center letter (target) of a five-letter string in which the target was either congruent (for example: MMMMM or NNNNN) or incongruent (for example: MMNMM or NNMNN) with the distracter letters. During each trial, flanking letters were presented 35 ms prior to target letter onset, and all five letters remained on the screen for a subsequent 100 ms (total trial time was 135 ms). Each trial was followed by a variable intertrial interval (1200–1700 ms) during which a fixation cross (+) was presented.

The experimental session included 480 trials grouped into six blocks of 80 trials during which accuracy and speed were equally emphasized. To elicit a sufficient number of errors for ERP analysis, letters making up the strings differed by block (e.g., M and N in block 1 and E and F in block 2), and mouse button-letter assignments were reversed at the midpoint of each block (e.g., left mouse-button click for M through 40 trials of block 1, then right-mouse button click for M for the last 40 trials of block 1). Characters were displayed in a standard white font on a black background and subtended 1.3° of visual angle vertically and 9.2° horizontally. All stimuli were presented on a Pentium R Dual Core computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli, the determination of response accuracy, and the measurement of reaction times.

After completion of the flanker task, participants filled out a packet of questionnaires including the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) and the Anxious Arousal (AA) subscale of the Mood and Anxiety Symptom Questionnaire (MASQ; Watson & Clark, 1991). The PSWQ was used as the measure of anxious apprehension and the MASQ-AA was used as the measure of anxious arousal per Nitschke et al. (2001).

Psychophysiological Recording and Data Reduction

Continuous encephalographic (EEG) activity was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 64 Ag-AgCl electrodes placed in a stretch-lycra cap in accordance with the 10/20 system in addition to two electrodes placed on the left and right mastoids. Electrooculogram (EOG) activity generated by eye movements and blinks was recorded at FP1 and three additional electrodes placed inferior to the left pupil and on the left and right outer canthi (all approximately 1 cm from the pupil). During data acquisition, the Common Mode Sense active electrode and Driven Right Leg passive electrode formed the ground, as per BioSemi's design specifications. All signals were digitized at 512 Hz using ActiView software (BioSemi).

Offline analyses were performed using BrainVision Analyzer 2 (BrainProducts, Gilching, Germany). Scalp electrode recordings were rereferenced to the numeric mean of the mastoids and band-pass filtered with cutoffs of 0.1 and 30 Hz (12 dB/oct rolloff). Ocular artifacts were corrected using the regression method developed by Gratton, Coles, and Donchin (1983). Physiological artifacts were detected using a computer-based algorithm such that trials in which the following criteria were met were rejected: a voltage step exceeding 50 µV between contiguous sampling points, a voltage difference of more than 200 µV within a trial, or a maximum voltage difference less than 0.5 µV within a trial. Trials were also rejected from ERP and behavioral analyses if the reaction time fell outside of a 200–800 ms time window and if accuracy was < 50% in the second half of a block, suggesting the participant failed to switch stimulus-response mappings (see above description of trial blocks). The response-locked data were segmented into individual epochs beginning 200 ms before response onset and continuing for 800 ms following the response. To quantify response-locked ERPs, a baseline equal to the average activity in the 200 ms window prior to response onset was subtracted from each data point subsequent to the response. The ERN and CRN were then quantified as the average voltage occurring in the 0–100 ms postresponse time window across five fronto-central recording sites (Fz, FC1, FCz, FC2, Cz). The Pe and its correct trial counterpart were quantified as the average voltage occurring in the 150–350 ms postresponse time window across five centro-parietal recording sites (Cz, CP1, CPz, CP2, Pz).

Data Analysis Strategy

Behavioral and ERP measures were statistically evaluated using SPSS General Linear Model software (Version 18.0). Measures with skewness or kurtosis values greater than 2 were transformed in order to normalize distributions. MASQ-AA scores were successfully log transformed. The arcsine transform was performed successfully for overall percent correct, post-error accuracy, and postcorrect accuracy. Descriptive statistics for these measures are reported using raw data, however. Repeated measures analyses of variance (ANOVAs) were first conducted on behavioral and ERP measures without regard to individual difference scores on the anxiety measures in order to establish baseline experimental effects. All ANOVAs included one two-level factor: Accuracy (error vs. correct). Subsequently, PSWQ and MASQ-AA scores were entered into separate ANOVAs as covariates in order to assess the main and interactive effects of anxious apprehension and anxious arousal on behavioral and ERP measures. Partial eta squared η_p^2 is reported as an estimate of effect size in ANOVA models where .05 represents a small effect, .1 a medium effect, and .2 a large effect (Cohen, 1973). When significant effects of anxiety scores were detected, follow-up correlational analyses are presented to aid in interpretation of results. Correlation coefficients (i.e., *r*s) ranging from .1–.23 are considered to represent small effects, *r*s ranging from .24–.36 represent medium effects, and *r*s greater than .37 represent large effects (Cohen, 1988). For a similar method, see Li, Zinbarg, and Paller (2007).

Results

Anxiety Measures

The average PSWQ score across the whole sample was 40.52 (*SD* = 12.89, range = 12–66). The average MASQ-AA score was 23.90 (*SD* = 6.13, range = 17–51). Consistent with theory and previous findings, overlap between the anxiety dimensions was

modest ($r = .27$, $p = .03$) compared to that between more coarse measures of anxiety (e.g., between the State Trait Anxiety Inventory and Beck Anxiety Inventory).

Performance Measures

As is typical for the flanker task, accuracy was quite high in the current study (M percent correct = 93.54%, $SD = 5.60$%). Overall accuracy was unrelated to the anxiety measures, however ($rs < .12$, $ps > .35$).

Participants exhibited faster reaction times (RTs) on error trials ($M = 372.71$, $SD = 52.65$) than on correct trials ($M = 449.54$, $SD = 41.74$; $F(1,64) = 276.36$, $p < .001$, $\eta_p^2 = .81$). Neither anxiety measure was significantly associated with overall RT, however ($Fs < 2.53$, $ps > .11$, $\eta^2 s_p < .04$).

Participants also showed significantly slower RTs following error trials ($M = 492.03$, $SD = 66.16$) than following correct trials ($M = 445.88$, $SD = 42.72$; $F(1,64) = 61.33$, $p < .001$, $\eta_p^2 = .49$)—the typical post-error slowing effect. Relationships between postresponse RT and PSWQ were nonsignificant ($Fs < 1$, $ps > .48$, $\eta^2 s_p < .01$). Entering the MASQ-AA as a covariate produced a nonsignificant main effect ($F < 1$, $p = .77$, $\eta_p^2 = .00$) and a significant Accuracy × MASQ-AA interaction effect ($F = 4.95$, $p = .03$, $\eta_p^2 = .07$). Follow-up correlational analysis showed that as MASQ-AA scores increased, so did post-error minus postcorrect RT ($r = .27$, $p = .03$).

Overall, participants were slightly more accurate after errors (M percent correct = 93.65%, $SD = 6.95$%) than after correct responses (M percent correct = 93.50%, $SD = 5.70$%; $F(1,64) = 8.23$, $p < .01$, $\eta_p^2 = .11$). Relationships between postresponse accuracy and PSWQ were nonsignificant ($Fs < 1$, $ps > .38$, $\eta^2 s_p < .02$). Entering the MASQ-AA as a covariate produced a nonsignificant main effect ($F = 2.79$, $p = .10$, $\eta_p^2 = .04$) and a significant Accuracy × MASQ-AA interaction effect ($F = 4.31$, $p = .04$, $\eta_p^2 = .06$). Follow-up correlational analysis showed that as MASQ-AA scores increased, post-error minus postcorrect accuracy decreased ($r = -.25$, $p = .04$).
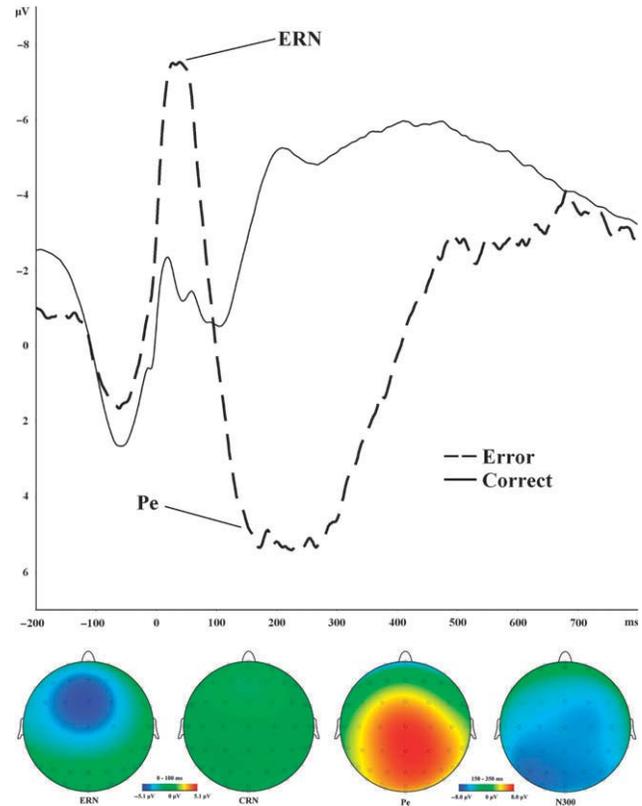
ERPs

ERN. Consistent with the literature, the main effect of Accuracy was significant ($F(1,66) = 70.47$, $p < .001$, $\eta_p^2 = .52$), indicating larger negativity on error ($M = -4.45$, $SD = 4.48$) compared to correct ($M = -1.01$, $SD = 3.66$) trials overall (see Figure 1).

When entered as a covariate, the main effect of PSWQ scores was significant ($F(1,65) = 5.52$, $p = .02$, $\eta_p^2 = .08$). The interaction between PSWQ scores and Accuracy was not significant ($F(1,65) = 2.36$, $p = .13$, $\eta_p^2 = .04$), however. Figure 2 shows response-locked ERPs for high- and low-PSWQ groups (top and bottom 25% of the distribution, respectively; for illustrative purposes only). As shown in Figure 3, follow-up correlational analysis showed that higher PSWQ scores were associated with greater postresponse negativity, irrespective of accuracy ($r = -.28$, $p = .02$).

Entering the MASQ-AA as a covariate produced no significant main ($F(1,65) = .08$, $p = .78$, $\eta_p^2 = .00$) or interaction ($F(1,65) = .53$, $p = .47$, $\eta_p^2 = .01$) effects. The correlation between MASQ-AA and overall postresponse negativity was negligible ($r = -.03$).

To further test the uniqueness of the relationship between anxious apprehension and postresponse negativity, we conducted a


Figure 1. Response-locked ERPs on error and correct trials recorded at electrode site FCz. Voltage maps displaying the distribution of activity on error and correct trials are presented at the bottom.

partial correlation between the PSWQ and overall postresponse negativity while controlling for MASQ-AA scores. The correlation between PSWQ and overall postresponse negativity remained significant after controlling for MASQ-AA scores (partial $r = -.28$, $p = .02$). Moreover, the correlation between PSWQ and overall
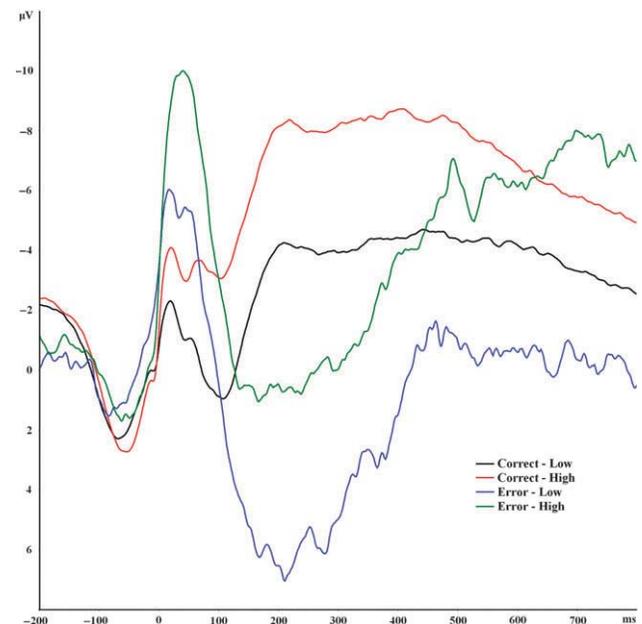
Figure 2. Response-locked ERPs on error and correct trials for bottom and top 25% of PSWQ distribution recorded at FCz.
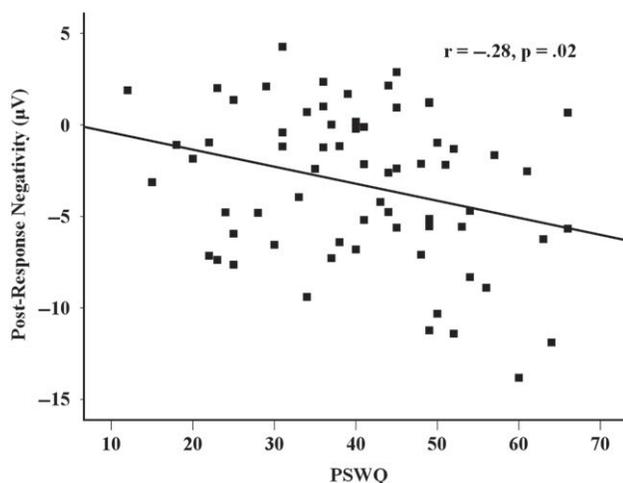
Figure 3. A scatter plot depicting the correlation between postresponse negativity amplitude (µV) and anxious apprehension (PSWQ).

postresponse negativity was larger than that between MASQ-AA and overall postresponse negativity ($Z = 1.71$, $p < .05$, one tailed).

Pe. Consistent with the literature, the main effect of Accuracy was significant ($F(1,66) = 299.91$, $p < .001$, $\eta_p^2 = .82$). As shown in Figure 1, a larger positivity was observed on error ($M = 6.47$, $SD = 6.58$) compared to correct ($M = -6.39$, $SD = 3.77$) trials overall.

When entered as a covariate, PSWQ scores demonstrated a significant main effect ($F(1,65) = 5.71$, $p = .02$, $\eta_p^2 = .08$; see Figure 2). Follow-up correlational analysis showed that higher PSWQ scores were associated with smaller postresponse positivity, irrespective of accuracy ($r = -.28$, $p = .02$). The interaction between PSWQ scores and Accuracy did not approach significance ($F(1,65) = 1.37$, $p = .25$, $\eta_p^2 = .02$).

Entering the MASQ-AA as a covariate produced no significant main ($F(1,65) < 1$, $p = .70$, $\eta_p^2 = .00$) or interaction ($F(1,65) < 1$, $p = .66$, $\eta_p^2 = .00$) effects. The correlation between MASQ-AA and overall postresponse positivity was negligible ($r = -.05$).

As with the ERN/CRN, controlling for MASQ-AA scores did not affect the correlation between PSWQ scores and overall postresponse positivity (partial $r = -.28$, $p = .02$). Directly comparing the correlation between PSWQ and overall postresponse positivity and that between MASQ-AA and overall postresponse positivity did not result in a significant difference, however ($Z = 1.57$, $p = .06$, one tailed).

Finally, we conducted a regression analysis in which we entered overall postresponse negativity and postresponse positivity to predict PSWQ scores. The overall model was significant ($F(2,64) = 3.73$, $p = .03$) and accounted for 8% of the variance in PSWQ scores. With both variables in the model, neither overall postresponse negativity nor postresponse positivity was a unique, significant predictor (βs $< .19$, ps $> .17$) suggesting that their covariance contributed to variance in PSWQ scores.

Discussion

The primary aim of the current study was to extend previous research by examining relationships between distinct dimensions of anxiety and action monitoring ERPs in an unselected sample of female undergraduates. Consistent with predictions, anxious apprehension—the worry dimension of anxiety—showed the strongest associations with action monitoring brain potentials. Specifically, higher anxious apprehension scores were associated with overall enhancements of ACC-mediated early action monitoring processes, as reflected in the ERN and CRN. Anxious apprehension was also related to overall reductions in later action monitoring activity, as reflected in the Pe and correct trial positivity. Anxious arousal, on the other hand, was unrelated to early or late action monitoring processes.

That anxious apprehension was associated with enhanced ERN and CRN magnitude is consistent with a previous group study of college students scoring high on the same measure of anxious apprehension used here (i.e., PSWQ; Hajcak et al., 2003) as well as several others in obsessive compulsive undergraduates (Hajcak & Simons, 2002) and patients (Endrass et al., 2008, 2010), who are also characterized by worry and verbal rumination. We significantly extend these previous group designs by showing an association between enhanced ERN and anxious apprehension measured along a continuum from mild to severe. Admittedly, only 6% of our subjects would have crossed threshold on the PSWQ for a diagnosis of GAD (see Behar, Alcaine, Zuellig, & Borkovec, 2003); however, (a) the range of scores reported by the subjects in the current study was sufficiently wide to apply to many different individuals, and (b) the primary aim of the current study was to demonstrate that relationships between anxiety and action monitoring extend to the full range of anxious apprehension symptoms. Our approach and findings are thus in line with available data and current conceptualizations suggesting that anxiety, and worry, in particular, are dimensional in nature (Brown & Barlow, 2009; Ruscio et al., 2001; Watson, 2005) and further support the 'continuity hypothesis' of psychopathology more generally (cf. Flett, Vredenberg, & Krames, 1997). That is, the relationship between anxiety and action monitoring functions is quantitative, not qualitative, such that greater anxious apprehension is associated with larger ERN/CRN amplitude whether measured continuously across a random sample of individuals—as was the case here—or categorically as in extreme group and patient studies. Extending the current approach to nonstudent groups is an important avenue for future research.

Anxious apprehension was also associated with reduced later action monitoring, as indexed by the Pe and correct positivity. This finding is consistent with a previous study showing reduced Pe and correct trial positivity in a group of undergraduates scoring high on a measure of negative affect (Hajcak et al., 2004). Reduced Pe in pathological groups has been interpreted as reflecting impaired awareness of and attention to mistakes (Hajcak et al., 2004; Olvet, Klein, & Hajcak, 2010). Other studies have yielded mixed findings with regard to the relationship between the Pe and anxiety (Endrass et al., 2008; Weinberg et al., 2010), however, and therefore the current effect should be considered with caution. Furthermore, visual inspection of the response-locked averages in Figure 2 and results from the regression analysis suggest that component overlap may be contributing to the reduced Pe in anxious apprehension—that is, the enhanced ERN may be contributing to the reduction of the subsequent Pe. *Post hoc* analysis further showed that the correlation between postresponse positivity and PSWQ scores was, in fact, a bit stronger at FCz ($r = -.33$) than at CPz ($r = -.27$; the sites of maximum amplitude for the ERN and Pe, respectively). Based on evidence suggesting a two-component structure of the Pe—one frontocentral and one centro-parietal (e.g., Arbel & Donchin,

2009)—future investigations should continue to carefully evaluate the unique relationship between the Pe and anxiety, accounting for its subcomponents and overlap with the ERN (e.g., by using principal components analysis).

Anxious arousal was not associated with early or late ERP indices of action monitoring processes. That anxious arousal was not associated with ERN/CRN or Pe/correct positivity is consistent with a previous study in spider phobic college students (Hajcak et al., 2003), who also failed to show differences in these components from controls. Our findings significantly extend this previous study in that we used a dimensional approach and measured anxious arousal more broadly rather than a narrow specific fear of spiders.

What then can we conclude about the relationship between anxiety and action monitoring ERPs? The current findings suggest that the anxious apprehension dimension is most clearly associated with action monitoring processes across multiple methods of analysis. Specifically, anxious apprehension was associated with enhanced ERN/CRN after controlling for anxious arousal and to a significantly greater degree than anxious arousal. A similar pattern of results emerged for the relationship between anxious apprehension and the Pe.

The isolation of a specific relationship between anxious apprehension and enhanced ERN/CRN has important implications for interpreting past findings from group studies. Because of the high co-occurrence of different forms of anxiety and their symptom overlap (for a review, see Brown & Barlow, 2009), it is difficult to determine from past studies that used extreme groups or patients diagnosed based on Diagnostic and Statistical Manual of Mental Disorders (DSM) criteria which aspect of anxiety contributed to relationships with action monitoring ERPs. The current findings therefore suggest that worry/verbal rumination may be the symptom dimension mostly responsible for previous findings in group studies of patients and undergraduate analogs. Thus, rather than enhanced ERN/CRN representing a generic correlate of internalizing psychopathology more generally as suggested by Olvet and Hajcak (2008), it may be that enhanced ERN/CRN is specifically associated with the cognitive component of anxiety. The advantage of utilizing psychometrically distinct dimensions of anxiety is that they are more likely to map onto basic biologic and genetic mechanisms like the ERN/CRN than are highly heterogeneous and overlapping categorical disorders (Bearden & Freimer, 2006; Krueger, 1999; Watson, 2005).

Honing the relationship between anxiety and action monitoring ERPs also has implications for delineating the functional significance of abnormal ERN/CRN in anxiety. Given relationships between anxiety and perfectionistic concerns about mistakes (for a review, see Egan, Wade, & Shafran, 2011), previous researchers have suggested that the enhanced ERN/CRN in anxiety reflects a physiologic manifestation of this maladaptive perfectionism (Weinberg et al., 2010). This interpretation also rests on findings suggesting that the ERN reflects the motivational significance of errors (Hajcak et al., 2005). Although there is no direct evidence for this claim, the current findings dovetail with this interpretation in that worry (Fergus & Wu, 2010) and anxiety disorders characterized by worry and verbal rumination such as GAD and obsessive compulsive disorder (OCD; e.g., Antony, Purdon, Huta, & Swinson, 1998) are associated with maladaptive concerns about mistakes. What is less consistent with this interpretation, however, is the fact that anxiety disorders characterized by anxious arousal such as panic disorder and social phobia also show elevated concerns about mistakes (for a review, see Egan et al.,

2011). Moreover, here, as in other previous work (e.g., Hajcak et al., 2003), we show that anxious apprehension is not uniquely associated with the ERN but rather relates to enhanced negativity on error and correct trials (i.e., CRN). Future studies directly testing associations between the ERN/CRN, different forms of anxiety, and concerns about mistakes are therefore warranted to further clarify the specific role of concerns about mistakes in linking anxiety to enhanced ERN/CRN.

Another possibility is that enhanced ERN/CRN in anxiety reflects overall inefficient action monitoring. That is, although more anxious individuals in the current study demonstrated enhanced action monitoring, they did not also show superior performance—consistent with previous studies (e.g., Hajcak et al., 2003), the current study revealed no association between anxious apprehension and behavioral performance. This notion fits well with research and theory suggesting a primary role of the ACC in optimizing performance by signaling the need for increased cognitive control in the face of information processing conflicts (Bartholow et al., 2005; Botvinick, 2007) and work suggesting that anxiety reduces the efficiency of frontal cortex-mediated cognitive control (Eysenck, Derakshan, Santos, & Calvo, 2007). Botvinick (2007) further suggests that the ACC not only signals the need for increased cognitive control in the face of conflicts or cognitive demand but also serves as a reinforcement signal for adopting strategies that minimize future conflicts and demands and maximize efficient information processing. In this context, then, anxious individuals' enhanced ERN/CRN suggests that cognitive conflicts and demands are chronically detected and therefore not well minimized, and that such exaggerated conflict signals simply equalize (do not optimize) performance (compared to nonanxious individuals). That our findings were specific to anxious apprehension, the very anxiety dimension theorized to be associated with cognitive inefficiency (Eysenck et al., 2007), further supports this interpretation.

In the broader context of research on dimensions of anxiety, the current findings fit with previous studies showing enhanced frontal cortex activity in anxious apprehensive individuals (Engels et al., 2007, 2010; Heller et al., 1997; Nitschke et al., 1999). These previous findings were revealed in resting state and emotional processing designs, and, therefore, the current study extends these findings to include enhanced frontal activation during response monitoring. One exciting avenue for future research would be to test associations between these different frontal activations.

Whereas anxious apprehension appeared to be associated with inefficient action monitoring—that is, exaggerated action monitoring brain activity and unaffected behavioral performance—anxious arousal showed no associations with action monitoring brain activity but rather demonstrated associations with ineffective behavioral performance. Specifically, anxious arousal was associated with increased post-error slowing and decreased post-error accuracy. In light of research linking anxious arousal to salience and threat detection, environmental scanning (Nitschke et al., 2000) and difficulty disengaging from emotional stimuli (Fisher et al., 2010), the current pattern of results suggests that individuals high in anxious arousal became more cautious following errors (i.e., slowed down more) but were unable to disengage from errors in order to effectively perform the next trial and thus were more likely to commit consecutive errors. The current results are also consistent with a recent study indicating the deleterious effects of anxious arousal on top-down control during emotion processing (Engels et al., 2010) and ex-

tend these effects to error processing. Additional research is necessary to further elucidate the impact of anxious arousal on cognitive task performance.

In sum, the current study extends previous research by showing that not all anxiety is associated with exaggerated action monitoring. Specifically, the current findings showed that the anxious apprehension—worry—dimension is uniquely associated with action monitoring processes. The current findings also extend the anxiety-action monitoring link to include the range of anxiety symptoms, thus suggesting a quantitative rather than a qualitative relationship between the two. Together, the current findings suggest specific rather than general associations between anxiety and action monitoring functions and the need to further clarify the functional significance of enhanced action monitoring in the development and maintenance of anxiety along the continuum of severity.

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