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The effect of expressive writing on the error-related negativity among individuals with chronic worry*

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Abstract

The error-related negativity (ERN), an ERP elicited immediately after errors, is enlarged among individuals with anxiety. The relationship between anxiety and enlarged ERN has spurred interest in understanding potential therapeutic benefits of decreasing its amplitude within anxious individuals. The current study used a tailored intervention—expressive writing—in an attempt to reduce the ERN among a sample of individuals with chronic worry. Consistent with hypotheses, the ERN was reduced in the expressive writing group compared to an unrelated writing control group. Findings provide experimental support that the ERN can be reduced among anxious individuals with tailored interventions. Expressive writing may serve to "offload" worries from working memory, therefore relieving the distracting effects of worry on cognition as reflected in a decreased ERN.

KEYWORDS

cognitive control, ERN, expressive writing, worry

1 | INTRODUCTION

The error-related negativity (ERN) is an ERP elicited 50–150 ms following an error in speeded choice tasks (Gehring, Goss, Coles, Meyer, & Donchin, 1993) at frontocentral recording sites. A plethora of studies have found the ERN to be enlarged among individuals with anxiety (Cavanagh & Shackman, 2015; Hajcak, 2012; Moser, Moran, Schroder, Donnellan, & Yeung, 2013), and this enlargement is thought to represent heightened sensitivity to internal threat (Weinberg et al., 2016) or compensatory effort among anxious individuals to perform well (Moser et al., 2013). The nature of this relationship has spurred interest in understanding how to modify this enlarged ERN among anxious individuals in order to illuminate neural mechanisms involved in therapueitc benefit to this population.

Thus far, studies that have examined the effects of traditional cognitive-behavioral interventions for anxiety disorders have demonstrated no measurable modulation of the ERN from pre- to posttreatment (Hajcak, Franklin, Foa, & Simons, 2008; Kujawa et al., 2016; Riesel, Endrass, Auerbach, & Kathmann, 2015). However, there is recent interest in developing other more targeted interventions to modify the ERN specifically (Meyer, 2016). Previous studies using cognitive behavioral therapy (CBT) may have failed to modulate the ERN because they were not tailored to addressing the underlying mechanisms driving enlarged ERN among anxious individuals. To test this notion, Nelson, Jackson, Amir, and Hajcak (2015) leveraged the threat sensitivity hypothesis of the ERN to motivate applying attention bias modification—that is, training attention away from negative information—to reduce the ERN. The authors reasoned that, if the ERN is a neural response to threatening information (i.e., an error), then attention bias modification should reduce the ERN. Consistent with this rationale, Nelson et al. found that the ERN was reduced following a single session of attention bias training. This study demonstrates the power of

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using more targeted interventions that consider the underlying mechanisms involved in the generation of the ERN.

Building on the rationale and findings of the Nelson et al. (2015) study, the purpose of the current investigation was to leverage knowledge about the benefits of another targeted intervention for anxiety, namely, expressive writing. Expressive writing involves writing down one's deepest thoughts and feelings about a particular event (Pennebaker & Beall, 1986). Although it is a simple intervention, this type of written emotional disclosure has been shown to relate to a number of positive outcomes—including improved immune functioning (Pennebaker, Kiecolt-Glaser, & Glaser, 1988), reduced distress for migraine sufferers (McKenna, 1997), fewer physican appointments (Richards, Beal, Seagal, & Pennebaker, 2000), and reduced anxiety, to name but a few (for a review and meta-analysis, see Frattarolli, 2006).

Of particular relevance to the current study, recent work by Ramirez and Beilock (Park, Ramirez, & Beilock, 2014; Ramirez & Beilock, 2011) showed that expressive writing prior to academic testing improves performance among anxious individuals. These authors argue that expressive writing frees up working memory resources by "offloading" distracting worrisome thoughts prior to testing that would have otherwise led to performance decrements. One study even found that the more participants wrote about their negative thoughts and feelings about the task at hand, the more their performance improved (Ramirez & Beilock, 2011). Indeed, other research indicates that expressive writing influences the relationship between intrusive thoughts and further distress (Lepore, 1997), such that the relationship is weaker after participants engage in expressive writing. Finally, studies also suggest expressive writing can improve working memory capacity (Kellogg, Mertz, & Morgan, 2010; Klein & Boals, 2001; Yogo & Fujihara, 2008). Together, this research suggests that expressive writing can offload worries to improve performance on the task at hand.

Ramirez and Beilock's (2011) rationale for the beneficial effects of expressive writing on peformance in anxious individuals was the primary motivation for the current study in which we tested whether expressive writing might lead to a decreased ERN in college students reporting clinical levels of worry. This prediction marries Ramirez and Beilock's aforementioned rationale with our compensatory error monitoring hypothesis (CEMH; Moser et al., 2013), which suggests that enlarged ERN in anxiety reflects compensatory cognitive control required to overcome the distracting effects of worries on working memory resources dedicated to active maintenance of task rules and goals. Together, we reasoned that expressive writing's effect of offloading worrisome thoughts from working memory would lead to less distraction and therefore a decreased need for compensatory cognitive control that would be reflected in a reduced ERN.

Thus, in the current study, college students with clinical levels of worry were randomly assigned to either an expressive writing or an unrelated writing control group before performing a flanker task employed to elicit the ERN. Three observations from the anxiety-ERN literature informed the design and predictions of this study. First, the subtype of anxiety that is most reliably associated with enlarged ERN is anxious apprehension (problematic worry; Hajcak, McDonald, & Simons, 2003; Moser et al., 2013). Thus, we recruited individuals who endorsed clinical levels of problematic worry. This approach allowed us to examine whether a targeted intervention can modify the ERN in a sample characterized by an enlarged ERN (i.e., worriers), which was not done in the previous study using attention bias modification as the targeted intervention (Nelson et al., 2015). Second, the anxiety-ERN association is strongest in females (Moran, Taylor, & Moser, 2012; Moser, Moran, Kneip, Schroder, & Larson, 2016), and so we recruited only females. Finally, the anxiety-ERN association is typically observed without any differences in behavioral performance (Moser et al., 2013). Thus, we predicted that expressive writing would reduce the ERN but have no impact on behavioral performance.

2 | METHOD

2.1 | Participants

A large sample of students ($N = 1{,}462$) from a Midwestern university were screened for chronic anxious apprehension using the Penn State Worry Questionnaire (PSWQ), a reliable and well-validated measure of trait worry (Brown, 2003; Meyer, Miller, Metzger, & Borkovec, 1990). Only participants scoring above 61 on the PSWQ, which is the standard cutoff for generalized anxiety disorder (GAD) on this measure (Behar, Alcaine, Zuellig, & Borkovec, 2003), were asked to participate in the EEG experiment. Twenty-seven percent of respondents ($N = 396$) met this criterion. Additional screening requirements included being female, normal or corrected-to-normal vision, right-handedness, and no history of a loss of consciousness for over 5 min. We exclusively recruited females because previous work indicates that the worry-ERN relationship is much greater in females (Moran et al., 2012; Moser et al., 2016) and because anxious apprehension is more prevalent in women (Kessler, Chiu, Demler, Merikangas, & Walters, 2005). These screenings produced 44 eligible female participants who provided written informed consent and participated in the current study. The university's Institutional Review Board approved all procedures.

Of the 44 eligible participants who completed the study, four participants were excluded prior to data analysis because they did not have at least six usable error-trial ERPs (Olvet

& Hajcak, 2009a), leaving a final sample of *N* = 40 (*M* age = 18.98, *SD* = 1.23; expressive writing condition, *n* = 21; unrelated writing condition, *n* = 19). The two groups were not significantly different in terms of age, *t*(38) = .13, *p* = .90. By design, participants in the final sample reported substantial worry symptoms (PSWQ, *M* = 68.68, *SD* = 5.79), at a level of severity that is on par with patients diagnosed with GAD (Brown, Moras, Zinbarg, & Barlow, 1993 [*M* = 68.11, *SD* = 9.59]; Brown, Antony, & Barlow, 1992 [*M* = 67.77, *SD* = 10.42]; Fresco, Mennin, Heimberg, & Turk, 2003 [*M* = 68.11, *SD* = 7.33]).

2.2 | Procedure

Figure 1 depicts the study design. After providing written informed consent, EEG cap and sensors were applied (see below for details). All experimental procedures (questionnaires, writing task, flanker task) were presented on a 19-in. LCD monitor using E-Prime 2.0 software (Psychology Software Tools, Sharpsburg, PA). Participants first completed the State-Trait Anxiety Inventory–State Version (STAI-S; Spielberger, Gorssuch, Lushene, Vagg, & Jacobs, 1983; α = .94 in the current sample). Next, participants were handed an envelope containing the specific instructions for their condition (experimenters were blind to the experimental condition). Instructions were nearly identical to those used in Study 2 of Ramirez and Beilock (2011; see online supporting information Appendix S1). Using the computer, participants wrote for 8 min. Care was taken to ensure that experimenters did not see the participants' writing at any time. As in Ramirez and Beilock, after the 8 min of writing, participants sat quietly for 4 min before they were given instructions about the computer task (participants were told that experimenters were setting up for the next part of the study). This additional time was provided for participants to reflect on what they had written. After the 4 min of rest, the experimenters returned to the experiment room and administered instructions for the flanker task.

2.2.1 | Flanker task

The task was a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1977). Participants were instructed to use the keyboard keys (left hand: *A* key; right hand: *L* key; response keys were covered with blank stickers) to respond to the center (target) letter of a five-letter string in which the target was either congruent (e.g., MMMMM or NNNNN) or incongruent (e.g., NNMNN or MMNMM) with the distracter letters. For example, during the first block, participants were to respond with a left-hand keyboard response if the target letter is *M*; a right-hand keyboard response was required for target letter *N*. 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 (1,200–1,700 ms) during which a fixation cross (+) was presented. Characters were displayed in a standard white font on a black background and subtended 1.3° of the visual angle vertically and 9.2° horizontally. All stimuli were presented using E-Prime software to control the presentation and timing of all stimuli, the determination of response accuracy, and the measurement of reaction times.

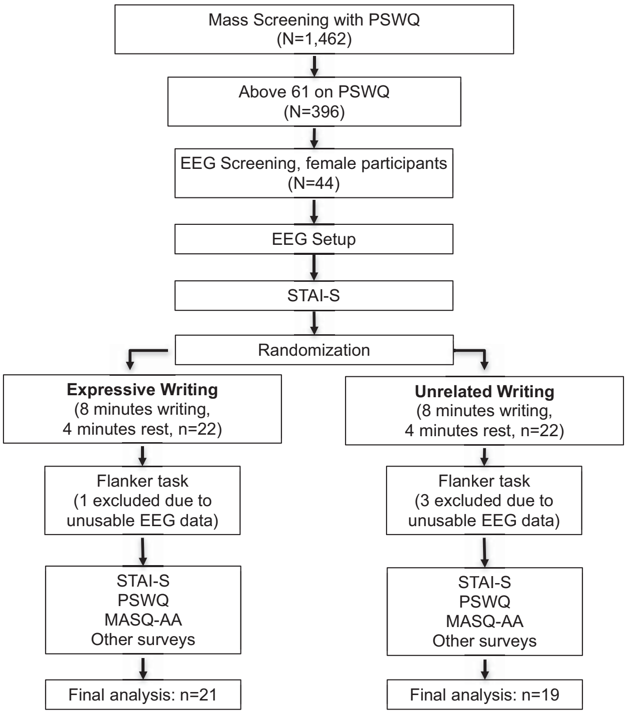

FIGURE 1 Study design

The experimental session included 480 trials grouped into 12 blocks of 40 trials during which accuracy and speed were equally emphasized. Across the entire task, the ratio of congruent to incongruent trials was kept at 1:1. To increase the number of errors and thus the number of error trials for reliable ERN analysis (Olvet & Hajcak, 2009a), letters making up the stimuli differed across the task (*M* and *N* in Block 1 and 2, *E* and *F* in Block 2 and 4, *O* and *Q* in Block 5 and 6, *T* and *I* in Block 7 and 8, *V* and *U* in Block 9 and 10, and *P* and *R* in Block 11 and 12), and stimulus-response mappings were reversed within each block pair (e.g., target *M* in Block 1 required left button response, whereas in Block 2 target *M* required a right button response).

2.2.2 | Self-report measures

Immediately after the flanker task, participants completed the STAI-S again (α = .94). After electrodes and cap were removed, participants completed the PSWQ (α = .79) and the Mood and Anxiety Symptom Questionnaire (MASQ;

Watson & Clark, 1991) Anxious arousal (MASQ-AA, $\alpha = .93$) subscale as part of a larger battery of questionnaires.[1] The MASQ-AA is composed of 17 statements related to physiological arousal (e.g., "felt numbness or tingling in my body") and asks participants to rate how much they have experienced these feelings, sensations, and problems during the previous week, including today, on a Likert scale ranging from 1 (*not at all*) to 5 (*extremely*).

2.3 | Psychophysiological recording and data reduction

Continuous EEG activity was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 64 Ag-AgCl electrodes placed in accordance with the 10/20 system. In addition, two electrodes were 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 (Brain Products, Gilching, Germany). Scalp electrode recordings were rereferenced to the numeric mean of the mastoids and bandpass filtered with cutoffs of 0.1 and 30 Hz (12 dB/oct rolloff). Ocular artifacts were corrected using the method developed by Gratton, Coles, and Donchin (1983).

Response-locked data were segmented into individual epochs beginning 200 ms before response onset and continuing for 800 ms following the response. Physiologic 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. The ERN and its correct-response counterpart (the correct-response negativity, CRN) were defined as the average activity in the 0–65 ms postresponse time window at electrode site FCz, where the ERN was maximal. Internal consistency of ERPs was examined with split-half reliability (i.e., correlation between odd-numbered trials and even-numbered trials) using the Spearman-Brown adjustment (see Olvet & Hajcak, 2009a). Coefficients for the ERN and CRN were .77 and .99, respectively.

2.4 | Text analysis

As a manipulation check, participants' essays were analyzed with the Linguistic Inquiry and Word Count (LIWC2007; Pennebaker, Chung, Ireland, Gonzales, & Booth, 2007). LIWC analyzes text documents and provides the percentage of different types of words (e.g., pronouns, affective words) used in a particular document. Previous work (Ramirez & Beilock, 2011) found the following categories to be sensitive to this type of expressive writing: anxiety words (worried, fearful, nervous), affect words (happy, cried, abandoned), positive emotion words (love, nice, sweet), negative emotion words (hurt, ugly, nasty), inhibition words (block, constrain, stop), cause words (because, effect, hence), and insight words (think, know, consider). Between-groups *t* tests were used for analyses of essay content.

2.5 | Self-reported anxiety analysis

Changes in STAI-S were assessed using a 2 (Time: pre- vs. postwriting manipulation) × 2 (Group: unrelated vs. expressive) analysis of variance (ANOVA). The other anxiety measures (PSWQ, MASQ-AA) were analyzed using independent *t* tests. We predicted that there would be no between-groups differences in any of the anxiety measures.

2.6 | Behavioral performance analyses

A univariate ANOVA with writing group (unrelated vs. expressive) as the independent variable was used to assess overall accuracy (% correct) differences. Reaction time (RT) data were submitted to a 2 (Response Type: error vs. correct) × 2 (Writing Group: unrelated vs. expressive) mixed model ANOVA. Similarly, standard congruency effects (i.e., longer RTs and poorer accuracy on incongruent trials, MMNMM, relative to congruent trials, NNNNN) were tested with a 2 (Congruency: congruent vs. incongruent) × 2 (Writing Group; unrelated vs. expressive) mixed model ANOVA.[2] We hypothesized that the two writing groups would not differ in terms of behavioral performance.

2.7 | ERP analysis

The primary hypothesis of the current study was that individuals in the expressive writing condition would show reduced ERN. The ERN effect was tested with a 2 (Response Type: error vs. correct) × 2 (Writing Group: unrelated vs. expressive) ANOVA. Partial eta squared (η_p^2) is reported as an estimate of effect size in ANOVA models where .05 represents a small effect, 0.1 a medium effect, and .2 a large effect (Cohen, 1973).

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[1] The other measures included in this packet assessed symptoms of depression, implicit theories, and cognitive interference that were not relevant to the present study and so were not analyzed here.

[2] Additional behavioral analyses are presented in the supporting information.

TABLE 1 Essay analyses using Linguistic Inquiry and Word Count (LIWC)

	Unrelated ($n = 19$)		Expressive ($n = 21$)		Independent samples *t* test			
Word category	***M***	***SD***	***M***	***SD***	$\lvert t \rvert$	***df***	***p***	$\lvert d \rvert$
Total words	333.00	94.56	325.48	105.65	0.24	38	.73	0.08
Affect (%)	2.02	1.40	6.47	2.31	7.28	38	< .001	2.36
Positive emotion (%)	1.47	0.98	3.75	1.67	5.18	38	< .001	1.69
Negative emotion (%)	0.52	0.60	2.52	1.19	6.59	38	< .001	2.14
Anxiety (%)	0.14	0.28	1.24	0.88	5.19	38	< .001	1.69
Cognitive mechanisms (%)	12.36	1.97	22.33	3.20	11.71	38	< .001	3.80
Insight (%)	0.99	1.21	4.30	1.93	6.41	38	< .001	2.08
Inhibition (%)	0.42	0.34	0.26	0.38	1.38	38	.18	0.45
Cause (%)	0.95	0.65	2.89	1.27	5.98	38	< .001	1.58

Note. Percentages refer to the average percentage of essays that included a particular word type.

3 | RESULTS

3.1 | Essay analysis

Essay analyses using LIWC software are presented in Table 1. Consistent with the intention of the writing manipulation, participants in the expressive writing group used a significantly higher percentage of words in every category tested (except for inhibition words), and the overall number of words did not differ between writing groups. Thus, the manipulation was successful in that participants in the expressive writing group used more affective words than those in the control group.

3.2 | Self-reported anxiety

Self-reported anxiety scores and between-groups analyses are presented in Table 2. The Time × Group ANOVA on STAI-S scores indicated no main effect of time, $F(1, 38) = 1.24$, $p = .27$, $\eta_p^2 = .03$, no main effect of group, $F(1, 38) = 1.25$, $p = .27$, $\eta_p^2 = .03$, nor an interaction between time and group, $F(1, 38) = 0.08$, $p = .80$, $\eta_p^2 = .002$. This suggests that neither writing exercise elicited significant anxiety. There were no between-groups differences in PSWQ scores before or after the writing exercise. Unexpectedly, however, we observed a significant difference between writing groups on the measure of anxious arousal (MASQ-AA) such that the expressive writing group reported higher MASQ-AA scores than the unrelated writing group (see Table 2).

3.3 | Behavioral performance

Behavioral performance data are presented in Table 3. Consistent with previous studies, accuracy on the flanker task was quite high. The typical speed-accuracy tradeoff was apparent in that RTs on error trials were significantly shorter than RTs on correct trials, $F(1, 38) = 11.02$, $p = .002$, $\eta_p^2 = .23$. Relative to congruent trials, incongruent trials

TABLE 2 Self-reported anxiety symptoms in the two writing conditions

	Unrelated ($n = 19$)		Expressive ($n = 21$)		Independent samples *t* test			
Measure	***M***	***SD***	***M***	***SD***	$\lvert t \rvert$	***df***	***p***	$\lvert d \rvert$
PSWQ screening	68.58	6.08	68.76	5.67	.10	38	.92	0.03
STAI-S preexperiment	32.79	9.73	37.09	12.43	1.21	38	.23	0.39
STAI-S postexperiment	34.68	12.59	38.24	12.50	.90	38	.38	0.29
PSWQ postexperiment	66.95	6.79	66.48	8.36	.19	38	.85	0.06
MASQ-AA postexperiment	27.47	11.59	38.10	14.73	2.52	38	.02	0.82

Note. PSWQ = Penn State Worry Questionnaire; STAI-S = State Trait Anxiety Inventory–State; MASQ-AA = Mood and Anxiety Symptom Questionnaire–Anxious Arousal.

TABLE 3 Behavioral performance measures and ERPs elicited from the flanker task

	Unrelated ($n = 19$)		Expressive ($n = 21$)		Independent samples t test			
Measure	***M***	***SD***	***M***	***SD***	$\lvert t \rvert$	***df***	***p***	$\lvert d \rvert$
Basic performance								
No. errors	33.32	18.66	36.48	22.10	0.49	38	.63	0.16
Accuracy (%)	92.80	4.22	92.16	4.82	0.44	38	.66	0.14
Error RT (ms)	399.86	70.44	413.96	60.63	0.68	38	.50	0.22
Correct RT (ms)	440.03	30.56	450.69	36.14	1.00	38	.32	0.33
Congruent RT (ms)	424.48	30.50	434.82	37.37	0.95	38	.35	0.31
Incongruent RT (ms)	456.75	32.16	468.07	35.76	1.05	38	.30	0.41
Congruency difference RT (ms)	32.26	14.89	33.25	14.18	0.22	38	.83	0.07
Congruent accuracy (%)	95.82	3.66	95.82	3.59	0.01	38	.99	0.00
Incongruent accuracy (%)	89.78	5.63	88.51	6.68	0.65	38	.52	0.21
Congruency difference accuracy (%)	6.04	4.40	7.32	4.72	0.88	38	.38	0.28
ERPs (μV)								
Error-related negativity (ERN)	−7.17	4.88	−5.71	4.19	1.02	38	.32	0.33
Correct-response negativity (CRN)	1.94	6.00	−0.35	3.19	1.53	38	.14	0.50
ΔERN	−9.11	6.40	−5.36	4.37	2.18	38	.035	0.71

Note. To retain positive values, congruency difference RT was calculated as incongruent RT minus congruent RT, and congruency difference accuracy was calculated as congruent accuracy minus incongruent accuracy. Average ERN amplitudes at FCz are reported.

were associated with longer RTs, $F(1, 38) = 203.19$, $p < .001$, $\eta_p^2 = .84$, and lower accuracy, $F(1, 38) = 85.15$, $p < .001$, $\eta_p^2 = .69$. In line with expectations, no behavioral differences emerged between writing groups.

3.4 | ERPs

Means, standard deviations, and *t* tests of ERP data are also presented in Table 3. Figure 2 presents data for response-locked waveforms. At the time of the response, errors elicited a larger negativity (i.e., the ERN) than correct responses, a significant main effect of response type, $F(1, 38) = 70.85$, $p < .001$, $\eta_p^2 = .65$, demonstrating the typical ERN waveform. Consistent with our main prediction, there was an interaction between response type and writing group, $F(1, 38) = 4.76$, $p = .04$, $\eta_p^2 = .11$, such that the difference between ERN and CRN was significantly reduced in the expressive writing condition compared to the unrelated writing condition, $t(38) = 2.18$, $p = .035$, $d = 0.71$.

4 | DISCUSSION

This study was designed to examine whether a brief, targeted intervention would impact the ERN among a group of anxious individuals. Although previous studies using traditional CBT techniques failed to modulate the ERN in anxious patients (Hajcak et al., 2008; Kujawa et al., 2016; Riesel, Endrass et al., 2015), one previous showed that an attentional bias modification procedure (Nelson et al., 2015)—a more targeted intervention—produced a smaller ERN relative to a control condition among healthy college students. In the current study, we built on the Nelson et al. finding by randomly assigning worriers to engage in expressive writing or a control writing condition. Expressive writing can also be considered a targeted intervention, given its effects on working memory resources (e.g., Kellogg et al., 2010) and performance (Ramirez & Beilock, 2011). Consistent with our hypothesis, we found a smaller ERN among worriers in the expressive writing condition compared to those in the unrelated writing condition. Below, we discuss implications of this finding.

Together with the Nelson et al. (2015) study, the current findings indicate that the ERN is more modifiable than previously thought and may not simply represent a static biomarker for anxiety risk (e.g., Olvet & Hajcak, 2008). Indeed, it is becoming increasingly clear that the anxiety-ERN relationship is quite specific. For instance, the anxiety-ERN relationship appears stronger in female samples (Moran et al., 2012; Moser et al., 2016), simple two-choice conflict tasks (Grundler, Cavanagh, Figueroa, Frank, & Allen, 2009; Riesel, Richter, Kaufmann, Kathmann, & Endrass, 2015) involving horizontal (vs. vertical) stimuli (Lin, Moran, Schroder, & Moser, 2015), and when trial-to-trial feedback is absent (Nieuwenhuis, Nielen, Mol, Hajcak, & Veitman, 2005; Olvet & Hajcak, 2009b). It is likely that interventions aimed at reducing the ERN in anxious populations will also need to be specific. According to the CEMH, the anxiety-

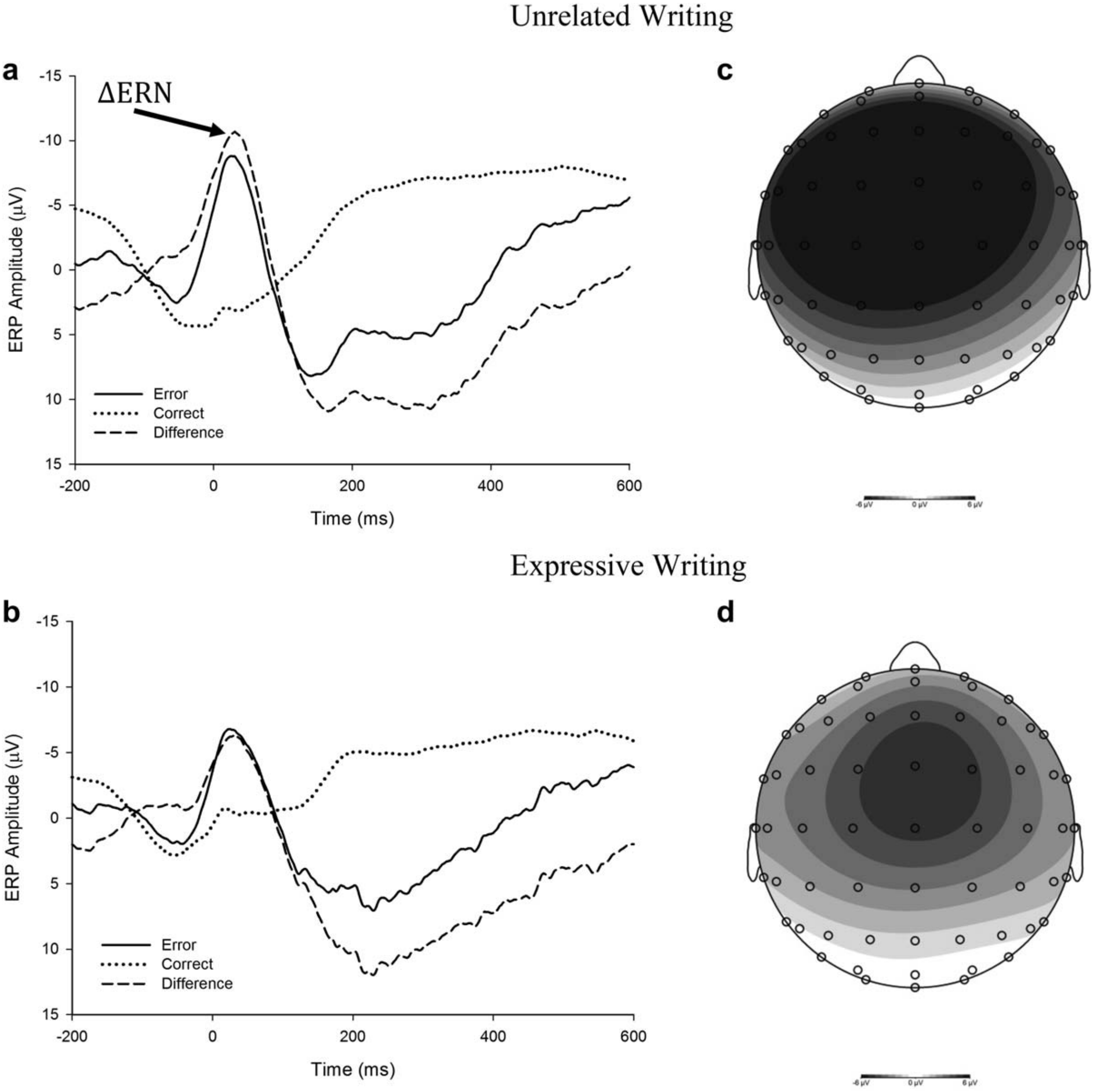

FIGURE 2 Error-related brain activity. Grand-averaged waveforms at electrode site FCz for the (a) unrelated writing condition ($n = 21$), and (b) expressive writing condition ($n = 19$). Time 0 represents response onset. Head maps of ERN difference in time window used in analysis (0–65 ms) for the (c) unrelated writing condition, and (d) expressive writing condition

ERN relationship depends on the extent to which worries drain cognitive resources resulting in a call for compensatory cognitive control (Moser et al., 2013). We therefore targeted this mechanism with expressive writing and found supportive evidence for its utility in reducing the ERN in worriers. However, without measuring working memory resources directly, we are unable to definitively conclude that expressive writing freed these resources to result in a reduced ERN. One recent and targeted study had individuals with and without obsessive-compulsive disorder (OCD) perform a combined *n*-back and flanker task to assess possible ERN modulation with high versus low working memory load (Klawohn, Endrass, Preuss, Riesel, & Kathmann, 2016). These authors found that placing additional demands on working memory resulted in a smaller ERN among both groups, and the reduction was larger in the OCD group. Although these findings may seem at odds with the current results—in which an intervention designed to free up the impact of worry on working memory resulted in a smaller ERN—the Klawohn manipulation also had an impact on behavioral performance, such that higher loads resulted in increased RT and higher error rates, with a larger increase in RT for the OCD group. It is possible that, by adding external working memory demands, there were fewer resources for individuals with OCD to employ compensatory effort, resulting in decreased ERN and poorer behavioral performance under the high-load conditions. In contrast, in our study there were no additional demands, but the expressive writing exercise may have decreased the "need" to engage compensatory effort, resulting in decreased ERN but no effects on behavioral performance. The discrepancies between the two studies may be the difference between an inability to compensate and compensation being unnecessary. It is likely that uncovering the reasons for these discrepancies may rely on more precise manipulation of working memory and an understanding of different error types. For instance, another recent study that combined a Sternberg memory task with a four-choice flanker task found that the effect of working memory on the ERN depended on error type: errors due to suboptimal selective attention were associated with a smaller ERN under high working memory load; in contrast, no working memory effect on the ERN was observed for "non-flanker" errors—errors committed for other reasons than selective attention (Maier & Steinhauser, 2017). Certainly, both the results of Klawohn et al. (2016) and those of our study suggest that working memory load is relevant to the anxiety-ERN relationship and deserves more attention. They also suggest that the ERN in anxious populations is more modifiable than previously thought.

Nonetheless, our findings provide an alternative intervention that may be used in modifying the ERN and to better understand the nature of the anxiety-ERN relationship. These findings highlight the need for targeted experimental designs to manipulate the ERN among individuals with clinical levels of anxiety. As mentioned earlier, three previous studies found that cognitive behavioral therapy did not reduce the ERN among patients with OCD, despite clinically meaningful symptom changes (Hajcak et al., 2008; Kujawa et al., 2016; Riesel, Endrass et al., 2015). Several differences between these previous studies and ours may help to explain the contrasting findings—that is, those studies focused on treatment-seeking individuals with an anxiety disorder, used different tasks, and assessed ERN several weeks into or after the intervention. We believe an especially important difference is the focus of the intervention; whereas these previous studies focused on reducing anxiety symptoms, the current study focused on reducing the impact of worries on cognitive resources. To be sure, more research is needed to understand the duration of the effects reported here.

4.1 | Limitations and future directions

Although the current study sheds light on the utility of expressive writing in reducing the ERN among worriers, there are limitations that should be addressed in future studies. First, the samples size ($N = 40$) was rather small for a between-subjects investigation, and, unfortunately, this is the rule rather than the exception in comparable cognitive neuroscience studies (Holmes & Pizzagalli, 2010; Klawohn et al., 2016; Olvet & Hajcak, 2012). Studies with larger sample sizes and a baseline (preintervention) measurement are needed to replicate the findings reported here and to confirm that expressive writing produces a within-subject decrease in ERN. Second, we examined the ERN only after participants engaged in the writing and were therefore unable to assess how these processes changed from before to after writing. However, previous studies employing pre-post designs have found that expressive writing improves performance in a way that is predicted by the current findings (Ramirez & Beilock, 2011). Third, we did not include a low-worry control condition. The purpose of the present study, however, was to provide a very specific test of the effects of expressive writing on the ERN in individuals with chronic levels of worry. Indeed, we meant to build upon the prior study that tested the effect of attention bias modification on the ERN (Nelson et al., 2015) by examining high-anxious individuals instead of college students sampled without regard for anxiety symptoms. Future studies drawing from a sample representing the full range of worry symptoms would also be able to assess how worry differentially correlates with the ERN in the control condition versus the expressive writing condition (cf. Ramirez & Beilock, 2011). We would expect a stronger correlation in the control condition than in the expressive writing condition. We were unable to examine this here because of a restricted range of worry scores. Fourth, because we utilized a student sample, it would be useful to examine the effects of expressive writing on the ERN in clinical samples in future studies. However, as we detailed in Method, the individuals in our sample reported worry symptoms that were comparable to previous studies of patients with GAD, and by using a well-validated measure in the PSWQ, it is likely that many of our participants had GAD. Moreover, college students are not immune to psychopathology. Previous studies have demonstrated high levels of psychological distress among this population (Hunt & Eisenberg, 2010).

Finally, although the writing conditions used here were identical to the ones used in previous studies (Ramirez & Beilock, 2011), the expressive writing condition differed from the control condition in two ways: it focused on emotion, and it focused on the upcoming task.[3] We are thus unable to discern whether the mechanism of action for the ERN reduction was due to the emotional writing or on writing related to the upcoming task. However, these previous studies contend that writing emotionally about the task at hand allows one to offload task-relevant worries and thoughts that might interfere with performance. We also contend that expressive writing is still more targeted than other traditional interventions (e.g., CBT; Kujawa et al., 2016) in which a host of mechanisms may be responsible for a change in the ERN.

All told, the current study provides an additional experimental option for future work on the modification of the

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[3] We thank an anonymous reviewer for pointing this out.

ERN. In addition to attention bias modification (e.g., Nelson et al., 2015), the expressive writing paradigm used here may be useful to adjudicate between competing hypotheses regarding the nature of the anxiety-ERN relationship in future studies. For instance, additional probes throughout the task to assess on-task sensitivity to the threat of errors (see Spunt, Lieberman, Cohen, & Eisenberger, 2012) or probes assessing on-task worry and effort may be used to address whether reductions in ERN are due to a reduction in threat sensitivity related to errors (e.g., Weinberg et al., 2016) or compensatory effort in the face of distracting worries (Moser et al., 2013). Our findings also build upon previous studies demonstrating the positive impacts of expressive writing (Frattarolli, 2006; Pennebaker et al., 1988; Ramirez & Beilock, 2011) by showing for the first time that this intervention can also reduce neural processing of mistakes in those who typically show exaggerated error monitoring. That the expressive writing group had reduced error monitoring but similar behavioral performance compared to the control group further suggests that it improved neural efficiency. We therefore conclude that expressive writing shows promise for alleviating the interfering impact of worries on cognition—as reflected in reduced error monitoring and intact performance—for those who need it most. We look forward to future studies testing these possibilities further.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Appendix S1
Table S1

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