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Empathy and error processing

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Abstract

Recent research suggests a relationship between empathy and error processing. Error processing is an evaluative control function that can be measured using post-error response time slowing and the error-related negativity (ERN) and post-error positivity (Pe) components of the event-related potential (ERP). Thirty healthy participants completed two measures of empathy, the Interpersonal Reactivity Index (IRI) and the Empathy Quotient (EQ), and a modified Stroop task. Post-error slowing was associated with increased empathic personal distress on the IRI. ERN amplitude was related to overall empathy score on the EQ and the fantasy subscale of the IRI. The Pe and measures of empathy were not related. Results remained consistent when negative affect was controlled via partial correlation, with an additional relationship between ERN amplitude and empathic concern on the IRI. Findings support a connection between empathy and error processing mechanisms.

Descriptors: Emotion, Event-related potentials, Cognitive control, Performance monitoring, Rabbitt effect, Anterior cingulate

Empathy is a critical component of pro-social behavior that includes the ability to affectively respond to the emotional state of another individual (Eisenberg, 2003; Hinnant & O'Brien, 2007). It is a complex form of psychological inference in which observation, memory, knowledge, and reasoning are combined to yield insights into the thoughts and feelings of others (Decety & Jackson, 2004; Ickes, 1997). Empathy is involved when people feel uncomfortable at another's shame, when spectators cringe while watching a crushing football tackle, or when average citizens rush to a disaster area desiring to help.

The neural bases of empathy are only beginning to be understood. Current hypotheses suggest empathy is related to the mirror neuron system (Iacoboni & Dapretto, 2006; Oberman & Ramachandran, 2007). That is, an automatic mimicking occurs at a neuronal level when humans observe another's actions, allowing the observer to simulate the emotions that accompany those actions and gain insight into the others' behaviors, thoughts, and feelings (Oberman & Ramachandran, 2007). Functional neuroimaging studies indicate empathy is related to activation of diverse neural networks including right inferior parietal cortex, somatosensory and insular cortices, limbic areas, and the anterior cingulate cortex (ACC; Chakrabarti, Bullmore, & Baron-Cohen, 2006; Decety & Lamm, 2007; Oberman & Ramachandran, 2007; Singer, 2006, 2007; Vollm et al., 2006).

Consistent with these findings, several studies indicate a significant role for the ACC in mediating human empathic responding (Seitz, Nickel, & Azari, 2006; Singer, 2006, 2007), with the highest levels of ACC activity during the interpretation of the affective dimensions of aversive events (Lamm, Batson, & Decety, 2006). Activation of the ACC in relation to empathy is also observed when individuals view another individual in pain (Morrison & Downing, 2007; Ochsner et al., 2008; Singer et al., 2004) and when evaluating the perceived 'fairness' of others' actions (Singer et al., 2006). The connection between ACC activity and empathic responding is not surprising given previous research indicating the ACC is critically involved in both emotional- and cognitive-control tasks (Carter & Van Veen, 2007; Egner, Etkin, Gale, & Hirsch, 2008; Vogt, Finch, & Olson, 1992).

One presumed reflection of ACC-mediated cognitive-control processes is the error-related negativity (ERN). The ERN is a fronto-medial maximal component of the scalp-recorded ERP that peaks within 100 ms of the commission of an error (Falkenstein, Hohnsbein, Hoormann, & Banke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The precise cognitive mechanisms generating the ERN remain the topic of considerable discussion (Burle, Roger, Allain, Vidal, & Hasbroucq, 2008; Holroyd & Coles, 2002; Yeung, Cohen, & Botvinick, 2004), but are primarily attributed to the cognitive control processes of detecting simultaneously competing response options, including errors (Van Veen & Carter, 2002; Yeung et al., 2004), a reinforcement-learning response to unexpected performance (Holroyd & Coles, 2002), or an affective/emotional response to errors (Compton et al., 2007; Larson, Perlstein, Stigge-Kaufman, Kelly, & Dotson, 2006; Luu, Collins, & Tucker, 2000; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). Source localization and fMRI studies consistently implicate a region in the ACC as the primary neural generator of the ERN (Van Veen & Carter, 2002).

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In addition to the ERN, other reflections of cognitive control and error processing include post-error response-time slowing and the post-error positivity (Pe). The Pe is a positive deflection in the ERP that occurs between 100 and 400 ms after the ERN. The functional significance of the Pe remains unclear (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005); however, the Pe may be associated with conscious error recognition, as it is diminished when subjects are unaware of on-line performance errors (Endrass, Reuter, & Kathmann, 2007; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Moreover, post-error RT slowing occurs primarily on trials that consist of an observable Pe (Mathalon et al., 2002; Nieuwenhuis et al., 2001), and Pe amplitude varies in relation to the degree of post-error slowing and autonomic nervous system activity (Hajcak, McDonald, & Simons, 2003b). Source localization studies of the Pe remain largely inconclusive, but suggest possible generators in either the caudal (Herrmann, Rommler, Ehlis, Heidrich, & Fallgatter, 2004) or ventral portions of the ACC (Overbeek et al., 2005).

Empathy and Error Processing

The similarity between brain regions involved in error processing (particularly the ERN) and cognitive and emotional control functions suggests a potential relationship between error-related neural activity and empathy. In a recent fMRI study, Lamm et al. (2006) showed alterations in ACC activity both when observing others in pain and when asked to take an 'other'-based, or empathic, perspective as opposed to focusing on their own response. In another study by Moriguchi et al. (2007), individuals with alexithymia, a marked deficit in differentiating self- or other-emotional states often seen in autism spectrum disorders (Hill, Berthoz, & Frith, 2004), were shown images of others in pain. Those with alexithymia displayed decreased activation in the left lateral prefrontal cortex, dorsal pons, cerebellum, and ACC relative to control participants. Further support for a possible relationship between empathy and error processing was uncovered by Newman-Norlund, et al. (2009). These investigators compared error processing and emotional content on a task that involved European soccer fans watching errors being committed by their favorite team and its rival. Errors were defined as missed penalty shots committed by either team. Results indicated that error-related activation of the ventral ACC was positively correlated with self-reported empathy.

Santesso and Segalowitz (2008) explored the possible relationship between reflections of error processing, particularly the ERN, and empathy/risk taking in a sample of 18–19-year-old males. Their findings confirmed a connection between risk-taking behaviors, empathy, and the ERN. Individuals who scored high on a measure of empathy showed increased ERN amplitude relative to those who scored lower on a measure of empathy. The same was true for risk-taking behaviors; individuals who endorsed more risk-taking behaviors showed attenuated ERN amplitude relative to their counterparts who endorsed fewer risk-taking behaviors. Risk taking and empathy each explained a unique aspect of the variance in recorded ERN amplitude.

Given these promising findings, we used multiple measures of empathy and negative affect to further explore the hypothesis that empathic responding is related to behavioral and electrophysiological manifestations of error processing. We sought to replicate and extend the work of Santesso and Segalowitz in five ways. First, we included multiple measures of empathy in order to determine the specific subcomponents of empathy (i.e., empathic concern, perspective taking, etc.) that are related to error processing. Second, we controlled for negative affect in our analyses due to previous research that indicates negative affect modulates both self-reported empathy levels and reflections of error processing (Dywan, Mathewson, Choma, Rosenfeld, & Segalowitz, 2008; Hajcak, McDonald, & Simons, 2004; Luu et al., 2000; Wiswede, Munte, Goschke, & Russeler, 2009). Third, we increased the potential generalizability of the results by including a sample of both males and females with an extended age range of 18 to 30 years. Fourth, we expanded our investigation to include the Pe component of the ERP. Fifth, we used error-trial minus correct-trial difference scores to control for between-subjects variability in ERP amplitudes and response times (RTs), allowing for a more precise interpretation of the relationship between error-related activity and empathy.

Methods

Participants

Participants were recruited from advertisements in the local community and undergraduate psychology courses. Study enrollment initially included 42 healthy individuals between the ages of 18 and 30. ERP data for one participant were lost due to equipment malfunction and 11 participants either showed too much movement-related artifact or made too few errors for reliable calculation of error-related ERPs (less than 7 usable error trials; these participants did not significantly differ from the final sample included in age, education, or self-reported empathy, anxiety, and depression scores). Thus, final study enrollment included 30 healthy, right-handed individuals (17 female). Demographic and participant summary information are presented in Table 1. Potential participants were excluded from the study if they endorsed a history of substance abuse or dependence, acquired brain disorders (e.g., traumatic brain injury with loss of consciousness or stroke), neurological disorders, or color-blindness. All participants had normal or corrected-to-normal vision and were provided either $10 or course extra credit for study participation. Study procedures were approved by the Institutional Review Board at Brigham Young University.

Experimental Task

Participants performed a modified color-naming version of the single-trial Stroop task. In this task, participants are presented with one of three words (RED, GREEN, BLUE) printed in one of the same three colors. Congruent trials were words presented in their same color of ink (e.g., the word BLUE printed in blue ink); incongruent trials included color-words printed in a different color of ink (e.g., the word BLUE printed in red ink). Participants were instructed to respond as quickly and accurately as possible to the color of ink while ignoring the word itself. Participants responded with a button press to one of three color-coded response keys using the index, middle, and ring fingers of their right hand. Color-to-key mapping was practiced prior to task performance using 50 presentations of each color-key combination. Each trial was 3 s in duration, with a Stroop color-word presented for 1.5 s followed by a 1.5 s fixation cross. Five blocks of 100 trials, with an equal distribution of congruent and incongruent trials (250 trials each), were presented.

Table 1. *Demographic and Mean (± SD) Summary Data*

Age (years)	21.63 (2.70)
Years of education	14.23 (1.24)
BDI-II score	7.37 (7.31)
STAI-State score	30.90 (7.42)
STAI-Trait score	34.27 (8.23)
EQ score	46.40 (13.79)
IRI Perspective Taking score	14.57 (3.05)
IRI Empathic Concern score	20.83 (4.41)
IRI Fantasy Subscale score	17.67 (5.64)
IRI Personal Distress score	9.77 (4.18)

Note: $N = 30$; BDI-II = Beck Depression Inventory—2nd Edition; STAI = State Trait Anxiety Inventory; EQ = Empathy Quotient; IRI = Interpersonal Reactivity Index.

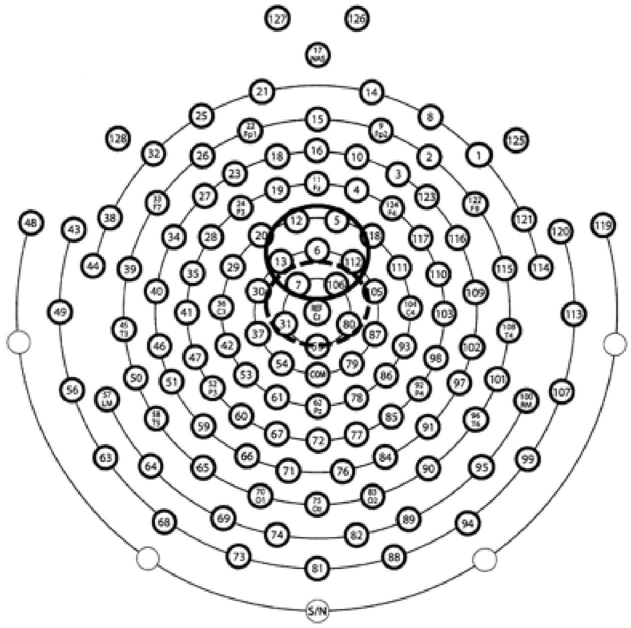

Figure 1. Sensor layout of the 128-channel geodesic sensor net (EGI, Eugene, Oregon). Solid-line circle indicates fronto-central recording sites averaged for ERN activity; dashed-line circle indicates central recording sites averaged for measurement of the Pe.

Electrophysiological Data Recording, Reduction, and Measurement

Electroencephalogram (EEG) was recorded from 128 scalp sites using a geodesic sensor net and Electrical Geodesics, Inc. (EGI; Eugene, OR) amplifier system (20K nominal gain, bandpass = .10–100 Hz). EEG was referenced to the vertex electrode (Cz) and digitized continuously at 250 Hz with a 24-bit analog-to-digital converter. Impedances were maintained below 50k Ω. Data were re-referenced to average mastoids off-line and digitally low-pass filtered at 15 Hz. Continuous EEG was segmented into condition-related epochs, and eye movement and blink artifacts corrected using the algorithm described by Gratton, Coles, and Donchin (1983).

Individual-subject response-locked averages were derived separately for correct and incorrect trials spanning 200 ms prior to and 500 ms following response. Epochs were baseline corrected using the 200 ms pre-response window. Trials containing errors of omission were excluded from averages. Electrode locations utilized were based on previous findings that the ERN and Pe are focal over fronto-medial locations and central areas, respectively (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring et al., 1993; Larson, Kaufman, Schmalfuss, & Perlstein, 2007; Larson et al., 2006; Overbeek et al., 2005). Error- and correct-trial amplitudes for the ERN were extracted as the average of 15 ms pre- to 15 ms post-peak negative amplitude between 10 ms and 90 ms and averaged across seven fronto-central electrode sites (numbers 5, 6, 7, 12, 13, 106 & 112—see Figure 1). Latency measurements for the ERN component were indexed as the peak negative-going amplitude within the 10 to 90 ms window averaged across the same fronto-central electrode locations. Error- and correct-trial amplitudes for the Pe were extracted as the average of 20 ms pre- to 20 ms post-peak positive amplitude within the 200 to 400 ms window of the epoch. Pe amplitude was measured as the averaged activity across five central electrode sites (7, 31, 80, 106, & Cz—see Figure 1).

Behavioral Measurement

Consistent with the procedures used by Santesso and Segalowitz (2008), RTs were calculated from Stroop stimulus onset to button press. Post-error slowing was defined as the mean RT for correct trials following error trials minus the mean RT for correct trials following correct trials.

Self-report Measures

All participants completed the Empathy Quotient (EQ; Baron-Cohen & Wheelright, 2004) and the Interpersonal Reactivity Index (IRI; Davis, 1980, 1983) as self-report measures of empathy and, given previous studies demonstrating differences in ERN amplitude as a function of negative affect (Compton et al., 2007; Compton et al., 2008; Hajcak, McDonald, & Simons, 2003a; Larson et al., 2006; Olvet & Hajcak, 2008; Ruchsow et al., 2006), participants also completed the Beck Depression Inventory—2nd Edition (BDI-II; Beck, Steer, & Brown, 1996) and the State-Trait Anxiety Inventory (STAI; Speilberger, Gorusch, Lushene, Vagg, & Jacobs, 1983).

Empathy Quotient. The EQ is a 60-item self-report measure that assesses empathic traits, including cognitive empathy, emotional reactivity, and social skills (Lawrence, Shaw, Baker, Baron-Cohen, & David, 2004). The EQ provides one total empathy score that has adequate test-retest reliability and concurrent validity with additional measures of empathy, including the IRI (Lawrence et al., 2004).

Interpersonal Reactivity Index. The IRI is a 28-item multidimensional measure of empathy that contains four seven-item subscales. The perspective taking (PT) subscale examines the tendency to adopt the psychological viewpoint of others. The empathic concern (EC) subscale assesses feelings of compassion and sympathy for others. The fantasy subscale (FS) examines the propensity to take the view of others in fictional situations. The personal distress (PD) subscale measures the tendency to experience emotional distress in response to perceived distress in others. The PT and FS subscales measure the cognitive aspects of empathy, while the EC and PD subscales assess the more emotional aspects of empathy (Alterman, McDermott, Cacciola, & Rutherford, 2003; Newman-Norlund et al., 2009). We examined only the individual subscales of the IRI, as there is no "total empathy score" associated with this measure (D'Orazio, 2004). The IRI has adequate internal consistency, test-retest reliability, and convergent validity with measures of social functioning, self esteem, emotionality, and sensitivity to others (Davis, 1980, 1983; Siu & Shek, 2005).

Beck Depression Inventory—Second Edition. The BDI-II is a 21-item self-report measure designed to assess the presence and severity of depression symptoms, with a primary emphasis on cognitive-affective and somatic symptoms (Beck et al., 1996; Storch, Roberti, & Roth, 2004). The BDI-II shows high levels of internal consistency, test-retest reliability, and concurrent validity with other self-report measures of depression and anxiety (Beck et al., 1996; Storch et al., 2004).

State-Trait Anxiety Inventory. The STAI is a 40-item measure of both state (i.e., short-term and situation-specific anxiety) and trait anxiety (i.e., long-term personality-based anxiety). The state and trait subscales each consist of 20 questions and yield separate state- and trait-anxiety scores. Both subscales of the STAI demonstrate adequate internal consistency and high levels of convergence with other measures of anxiety (Speilberger et al., 1983).

Statistical Analysis

Median correct-trial RTs, arcsine transformed error rates (Neter, Wasserman, & Kutner, 1985) excluding non-response trials, and ERP component amplitude and latency data were used as the dependent variables. Median RTs were used as suggested by Ratcliff (1993) to reduce the impact of outlier RTs and due to the positive skew frequently associated with RT data. Arcsine-corrected error rates were used to normalize the data due to a positive skew frequently associated with error-rate data (Neter et al., 1985). Differences between congruent and incongruent trials, and/or error and correct trials, for RTs, error rates, and ERP indices were examined using within-subjects paired-samples *t*-tests. Pearson's product-moment correlations were utilized to determine the relationship between empathy and behavioral- (i.e., post-error slowing) and electrophysiological- (i.e., ERN and Pe) indices of error processing. Subsequent partial correlations controlled for the potential contributions of negative affect to the relationship between empathy and indices of error processing. Multiple regression analyses with the error-trial minus correct-trial difference score as the dependent variable were used to determine the unique correlates of empathy and ERN amplitude.

Table 2. *Mean (± SD) Response Times (Milliseconds), Error Rates (Percent), and Degree of Post-error Slowing on the Stroop Task. Response Times Represent the Mean of Individual Median RTs*

Response Times	
Congruent correct trials	539.75 (82.63)
Incongruent correct trials	613.40 (121.56)
All correct trials	571.83 (99.64)
Congruent error trials	505.25 (123.21)
Incongruent error trials	630.38 (150.16)
All error trials	585.43 (142.13)
Post-error slowing all trials	100.58 (86.15)
Post-error slowing congruent	70.25 (100.58)
Post-error slowing incongruent	123.68 (127.61)
Error rates	
Congruent trials	.03 (.02)
Incongruent trials	.06 (.03)

Results

Behavioral Performance

Response times, including post-error slowing, and error-rates for the Stroop task are presented in Table 2. Error rate and RT data were not significantly correlated, $r = -.21$, $p = .26$, indicating a speed-accuracy trade-off was not a significant factor in participant performance. Participants showed robust Stroop RT-related interference, with longer RTs to incongruent relative to congruent trials, $t(29) = 7.76$, $p < .001$. Similarly, participants showed Stroop error-rate interference, with significantly higher error rates for incongruent compared to congruent trials, $t(29) = 5.76$, $p < .001$. Considerable post-error slowing of RTs was evident on trials following errors relative to trials following correct responses collapsed across congruency, $t(29) = 6.39$, $p < .001$, as well as on congruent, $t(29) = 3.83$, $p < .001$, and incongruent trials, $t(29) = 5.31$, $p < .001$, individually.

Event-related Potential Data

Response-locked correct-trial waveforms contained an average (± *SD*) of 446.40 (± 29.87) trials, whereas response-locked error-trial waveforms contained an average of 19.00 (± 10.71) trials. Grand average ERP waveforms and spline-interpolated voltage maps for correct and error response-locked trials reflecting the fronto-medial ERN are shown in Figure 2; those for the central Pe are shown in Figure 3. Mean (± *SD*) component amplitude data are presented in Table 3.

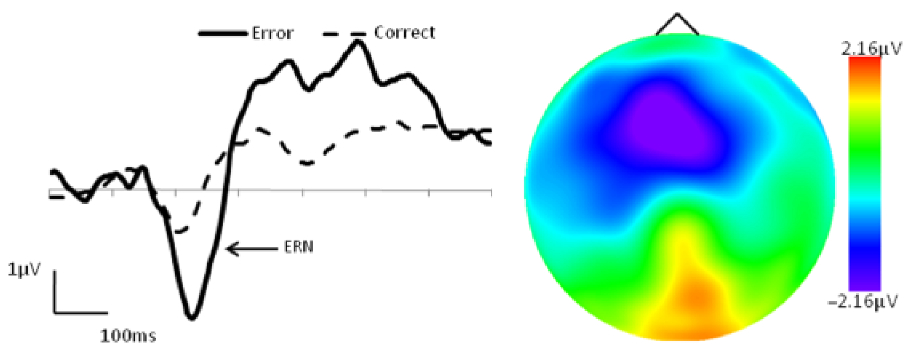

Figure 2. Grand average ERP waveforms depicting response-locked correct- and error-related activity averaged across fronto-medial electrode locations for the ERN and the top view of the spline-interpolated voltage distribution maps showing mean voltages for the error- minus correct-trial difference.

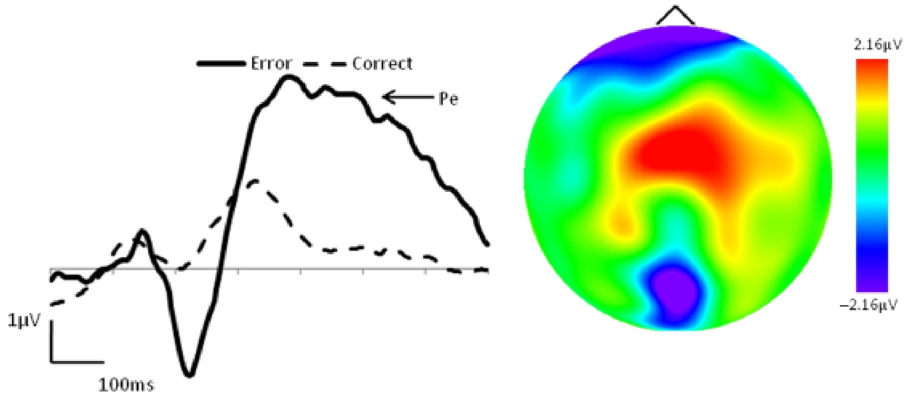

Figure 3. Grand average ERP waveforms depicting response-locked correct- and error-related activity averaged across central electrode locations for the Pe and the top view of the spline-interpolated voltage distribution maps showing mean voltages for the error- minus correct-trial difference.

Consistent with expectations, response-locked ERPs averaged across fronto-central electrodes showed a negative deflection that peaked at approximately 31 ms and was larger in amplitude to error- than correct-trials, $t(29) = 3.88$, $p < .001$, indicating the presence of a statistically reliable ERN. Comparison of error- and correct-trials for the Pe averaged across central electrode locations was also significant, $t(29) = 6.33$, $p < .001$, indicating the presence of a statistically reliable Pe waveform.

Empathy and Error Processing

We used zero-order correlations to determine the relationship between measures of empathy (i.e., the EQ and the four subscales of the IRI) and both behavioral (i.e., post-error slowing) and electrophysiological (i.e., ERN and Pe) measures of error processing (see Table 4). For behavioral data, since reliable post-error slowing was present following both congruent and incongruent trials, correlations were conducted between measures of empathy and the post-error minus post-correct trial difference collapsed across congruencies. For ERP data, correlations were conducted between measures of empathy and the error-trial minus correct-trial difference wave for the ERN and the Pe collapsed across congruencies. The difference wave was chosen to account for potential between-subjects variability in amplitude from baseline for both correct and error responses and to isolate error-related ERP activity, although we also present the correlations with error-trial and correct-trial waveforms for both the ERN and the CRN in Table 4.

Post-error slowing was significantly associated only with the PD subscale of the IRI, $r = .37$, $p < .05$, indicating increased post-error slowing in individuals who endorsed increased levels of emotional distress in response to perceived distress in others. For electrophysiological indices, the error-trial minus correct-trial difference representing the ERN was inversely associated with EQ score, $r = -.36$, $p < .05$, indicating larger-amplitude ERN is associated with increased self-reported empathy score. Difference score for the ERN was also inversely related with the FS subscale of the IRI, $r = -.40$, $p < .05$. There were no significant relationships between Pe amplitudes and measures of empathy. Scatter plots for significant correlations between ERP indices and empathy measures are presented in Figure 4.

To determine the potential unique contributions of the EQ score and FS subscale score to ERN amplitude, we entered them into a regression model with ERN error-trial minus correct-trial difference score amplitude as the dependent variable. When put into the model together, neither EQ score, $B = .01$, $SE\ B = .02$, $t = .65$, $p = .53$, nor FS subscale score, $B = .06$, $SE\ B = .05$, $t = 1.25$, $p = .22$, had a unique contribution to ERN difference score amplitude, *full model* $R^2 = .18$, $p = .07$.

Given previous research indicating ERN amplitude is modulated by affective symptomatology (Compton et al., 2007; Compton et al., 2008; Dywan et al., 2008; Hajcak et al., 2003a; Olvet & Hajcak, 2008; Ruchsow et al., 2006), we next conducted the same series of correlations listed above as partial correlations controlling for BDI-II, STAI-State, and STAI-Trait scores. As can be seen in Table 5, the relationship between post-error slowing and the PD subscale of the IRI remained statistically reliable and was enhanced relative to the initial correlations when controlling for negative affect, $r = .52$, $p < .01$. Similarly, the inverse relationship between the error- minus correct-trial ERN difference and EQ score remained statistically reliable, $r = -.44$, $p < .05$. The relationship between ERN difference score and the FS subscale of the IRI also remained significant, $r = -.41$, $p < .05$, while an additional inverse relationship between ERN difference score and the EC subscale of the IRI surfaced, $r = -.43$, $p < .05$. No significant relationships between Pe difference score and measures of empathy were present when negative affect was controlled for via partial correlation. A multiple regression that included the measures of negative affect as well as the EQ score and FS and EC subscale scores was also not significant, *full model* $R^2 = .26$, $p = .28$, with no unique predictors, $B\text{s} < .05$, $t\text{s} < .88$, $p\text{s} > .39$.

Table 3. *Mean (± SD) ERP Amplitude (μV) Data for Error- and Correct-trials for the Fronto-central Error-related Negativity (ERN) and the Central Post-error Positivity (Pe)*

	ERN	Pe
	Amplitude (μV)	
Correct trial	−.94 (.77)	.63 (.96)
Error trial	−1.79 (1.35)	3.21 (2.10)
Error minus correct difference	−.85 (1.19)	2.58 (2.23)

Discussion

The purpose of this study was to further examine the relationship between error processing and empathy. Consistent with our predictions and one previous study (Santesso & Segalowitz, 2008), increased levels of self-reported empathy were reliably associated

Table 4. *Zero-order Correlations Between Measures of Empathy and Behavioral and Event-related Potential Indices*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Incongruent – Congruent RT	1.00													
2. Error Rate	– .05	1.00												
3. Post-error Slowing	.28	– .31	1.00											
4. ERN Amplitude	.15	.24	.18	1.00										
5. CRN Amplitude	.42*	– .08	.07	.47**	1.00									
6. Error – Correct ERN	– .10	.32	.16	.82**	– .12	1.00								
7. Error Pe Amplitude	– .04	– .43*	– .03	– .25	– .05	– .25	1.00							
8. Correct Pe Amplitude	.14	– .13	– .14	– .05	.07	– .10	– .05	1.00						
9. Error – Correct Pe	– .09	– .34	.03	– .21	– .08	– .19	.90**	– .38*	1.00					
10. EQ Total	.18	.17	– .04	– .36*	– .08	– .36*	– .07	– .20	.02	1.00				
11. IRI Perspective Taking	– .22	.11	.18	– .29	– .13	– .24	.02	– .25	.12	.29	1.00			
12. IRI Fantasy	.19	.02	– .13	– .30	.10	– .40*	.20	– .23	.28	.68**	.36*	1.00		
13. IRI Empathic Concern	.12	.04	– .02	– .23	.07	– .30	.05	– .26	.16	.87**	.37*	.68**	1.00	
14. IRI Personal Distress	.29	– .21	.37*	.26	.14	.20	– .29	.07	– .30	– .34	– .09	– .15	– .37*	1.00

Note: RT = Response time; ERN = Error-related negativity; CRN = Correct-response negativity; Pe = Post-error positivity; EQ = Empathy Quotient; IRI = Interpersonal Reactivity Index.
*$p<.05$, **$p<.01$.

with increased ERN amplitude. Increased ERN amplitude was also associated with the fantasy subscale of the IRI. Post-error slowing, in contrast, was not related to general trait empathy, but was reliably associated with the tendency to experience personal emotional distress when perceiving that others are emotionally distraught (i.e., personal distress subscale of the IRI). The overall pattern of behavioral and ERP results either remained consistent, or were magnified, when measures of negative affect were accounted for in the analyses. Further, a relationship between ERN amplitude and the empathic concern subscale of the IRI emerged only after controlling for measures of negative affect. These results suggest the relationship between empathy and the ERN is not simply the consequence of a person's affective state and that negative affect may actually obscure the unique relationship between empathic concern and the ERN. Importantly, the relationship between measures of empathy and the ERN were present only for error-trial or error-trial minus correct-trial ERP amplitudes, indicating a specific relationship between error-processing indices and empathy, rather than a relationship with general ERP reactivity. Multiple regression analyses revealed separate measures of empathy did not uniquely contribute to the prediction of ERN amplitude. These findings indicate a high degree of overlap in the variance accounted for by the separate empathy measures and a likely underlying latent construct that

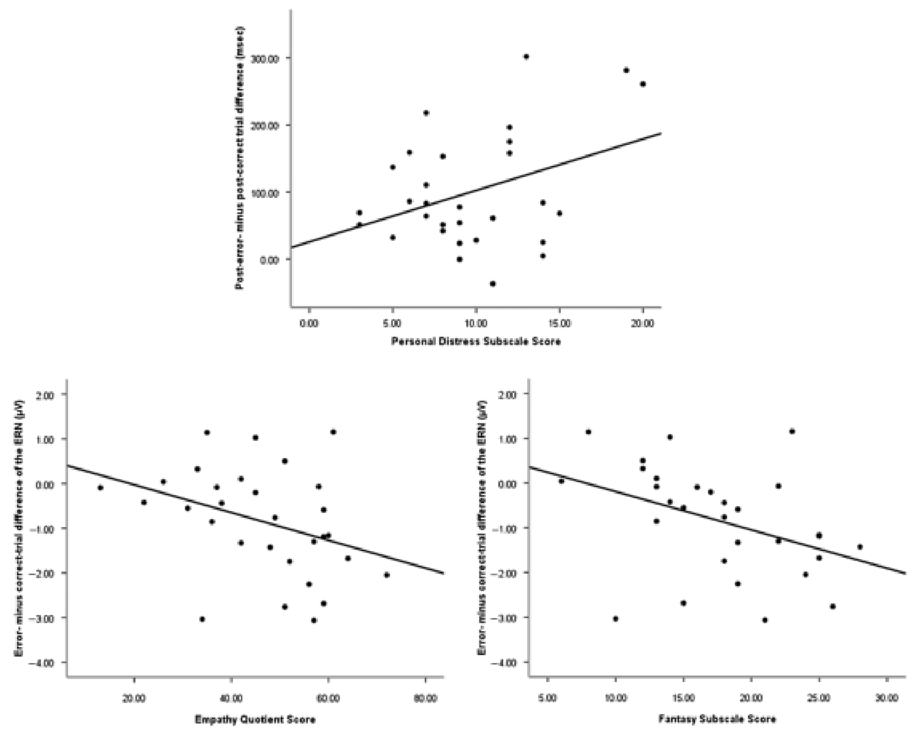

Figure 4. Scatter plots (in clockwise order) for the post-error- minus post-correct-trial RT difference score and the Personal Distress subscale of the IRI; error- minus correct-trial difference for the ERN and the Fantasy Subscale score of the IRI; error- minus correct-trial difference for the ERN and the Empathy Quotient score.

Table 5. *Partial Correlations Between Measures of Empathy and Behavioral and Event-related Potential Indices Controlling for Beck Depression Inventory—Second Edition (BDI-II) and State-Trait Anxiety Inventory (STAI) Scores*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Incongruent – Congruent RT	1.00													
2. Error Rate	− .02	1.00												
3. Post-error Slowing	.25	− .28	1.00											
4. ERN Amplitude	.14	.28	.15	1.00										
5. CRN Amplitude	.41*	− .06	.05	.46*	1.00									
6. Error – Correct ERN	− .11	.35	.14	.83**	− .12	1.00								
7. Error Pe Amplitude	− .13	− .47*	− .10	− .25	− .06	− .24	1.00							
8. Correct Pe Amplitude	.16	− .13	− .15	− .05	.09	− .11	.08	1.00						
9. Error – Correct Pe	− .19	− .36	− .02	− .20	− .10	− .16	.88**	− .41*	1.00					
10. EQ Total	.14	.23	− .15	− .42*	− .05	− .44*	− .33	− .25	− .19	1.00				
11. IRI Perspective Taking	− .26	.12	.17	− .29	− .11	− .25	− .09	− .27	.04	.19	1.00			
12. IRI Fantasy	.16	.03	− .19	− .28	.15	− .41*	− .01	− .25	.11	.64**	.30	1.00		
13. IRI Empathic Concern	.06	.10	− .16	− .30	.15	− .43*	− .22	− .36	− .03	.82**	.29	.67**	1.00	
14. IRI Personal Distress	.38*	− .28	.52**	.34	.17	.28	− .29	.09	− .31	− .27	− .05	− .14	− .28	1.00

Note: RT = Response time; ERN = Error-related negativity; CRN = Correct-response negativity; Pe = Post-error positivity; EQ = Empathy Quotient; IRI = Interpersonal Reactivity Index.
*$p < .05$, **$p < .01$.

accounts for the relationship between empathy and ERN amplitude.

One possible construct that may explain the relationship between the ERN and empathy is vigilance to performance and the environment. Several studies indicate ERN amplitude is modulated by vigilance. For example, ERN amplitude is increased when individuals are instructed to be vigilant to the accuracy of their responses, relative to the speed of their responses (Gehring et al., 1993). Similarly, errors committed while being observed or during conditions of high reward, both presumably involving increased vigilance, are associated with larger ERNs (Hajcak, Moser, Yeung, & Simons, 2005). Increased ERN amplitudes are also seen in individuals with high levels of anxiety, a condition associated with increased vigilance to performance and the world around them (Compton et al., 2007; Endrass et al., 2007; Hajcak et al., 2003a), and in individuals with personality profiles associated with increased task engagement, such as high agreeableness and behavioral shame (Topps, Boksem, Wester, Lorist, & Meijman, 2006). Empathy requires vigilance both to the environment and the actions of others. Preliminary research conducted chiefly using animal models suggests that, when discomfort is detected in another, one's vigilance toward the environment increases and brain regions associated with responsiveness to direct threat are activated (Chen, Panksepp, & Lahvis, 2009; Knapska et al., 2006; Mateo, 1996). Vigilance, then, involves monitoring of both one's own performance and reactions as well as monitoring the emotional state of others (i.e., vigilance requires both cognitive and emotional control).

Another possible explanation for the relationship between ERN amplitude and empathy is an underlying concern for positive or successful outcomes. According to Batson (1991), pro-social behaviors, such as empathy and altruism, have the purpose of improving the well-being of an individual in distress. By demonstrating empathy for someone in distress, the likelihood of the distressed individual feeling understood and cared for increases, thereby facilitating improved affect and a subsequent positive (i.e., successful) outcome for those involved. We should note, however, that exhibiting empathy does not necessarily ensure pro-social behavior. For example, an individual could use their 'empathic' cognitive and emotional abilities to exploit another's weakness or vulnerability by better understanding their experience (Hein & Singer, 2008). If empathy were framed in this context, the concern for outcomes would pertain to personal, selfish motives, rather than for the benefit of others.

Findings of a relationship between ERN amplitude and empathy are consistent with theories indicating the ERN is associated with attention to not only cognitive variables, but also emotional/affective variables (Compton et al., 2007; Dywan et al., 2008; Larson et al., 2006; Luu et al., 2000; Santesso & Segalowitz, 2008). Likewise, empathy requires the affective component of sharing an emotional experience with another individual and a cognitive component of understanding that experience (Decety & Jackson, 2004). Examples of individuals who experience difficulties in both emotional- and cognitive-control component processes are those with autism spectrum disorders. These individuals frequently show deficits in the ability to share emotional experiences with others and cognitively understand those experiences (Lawrence et al., 2004). It is not surprising, therefore, that research is beginning to show alterations in ERN amplitude and latency across the autism spectrum (Henderson et al., 2006; Vlamings, Jonkman, Hoeksma, van Engeland, & Kemner, 2008).

Despite the finding of considerable overlapping variance between the measures of empathy, the correlations between the ERN and the fantasy and empathic concern subcomponents of empathy remain of considerable theoretical interest. The relationship between ERN amplitude and the fantasy subscale of the IRI was unexpected. The fantasy subscale is associated with an increased level of emotional responding as well as introverted behaviors such as social anxiety, shyness, and feelings of loneliness (Davis, 1983). High scores on the fantasy subscale are also frequently seen in individuals who are isolated, uncomfortable, and hypervigilant in social situations (Fontenell et al., 2009). As noted above, increased ERN amplitudes are also commonly seen in individuals with heightened levels of anxiety (Compton et al., 2007; Hajcak et al., 2003a). Thus, it is possible that the covariation between ERN amplitude and fantasy subscale scores is mediated by social anxiety and increased vigilance and concern associated with making an error. This possibility, along with the aforementioned studies indicating alterations of ERN amplitude in individuals with autism spectrum disorders, suggests a relationship between social behaviors/social vigilance and the cognitive and emotional monitoring processes related to the ERN. The findings of altered ERN amplitudes in individuals with poor socialization and high levels of psychopathic personality traits (Dikman & Allen, 2000; Munro et al., 2007; Santesso, Segalowitz, & Schmidt, 2005) are also consistent with this possibility.

There was also an interesting relationship between ERN amplitude and empathic concern. In the original work on the IRI, Davis (1983) indicates empathic concern primarily involves feelings of compassion and sympathy associated with seeing another in distress. That is, empathic concern is a mirroring of the emotional state of another individual. Recent research, however, suggests empathic concern is more of a complementary emotional response that, in addition to mirroring the emotional state of another individual, requires the regulation of negative affect to feel compassion for the other individual and regulate one's own emotions associated with viewing another in distress (Newman-Norlund et al., 2009). Empathic concern in the current study may, therefore, be related to the regulation of negative affect associated with error commission. Consistent with this possibility, a previous fMRI study demonstrated a relationship between empathic concern and error-related ACC modulation (Newman-Norlund et al., 2009) and additional studies demonstrate increased ERN amplitude associated with higher levels of negative affect (Dywan et al., 2008; Hajcak et al., 2004; Luu et al., 2000; Wiswede et al., 2009). However, the relationship between empathic concern and the ERN only emerged when the variance associated with negative affect was statistically accounted for. This suggests a large overlap between general negative affect and empathic concern (the correlation between the negative affect factor and the empathic concern subscale of the IRI was .93, $p < .001$) and that high levels of negative affect actually suppress the relationship between ERN amplitude and empathic concern. Given these competing possibilities, it is unclear exactly what constitutes the unique relationship between empathic concern and ERN amplitude. One possibility is that when general negative affect was controlled for the anxiety associated with making an error and vigilance to task performance remained. Future research isolating the participants' affective response to errors, degree of general negative affect, and level of empathic concern is needed to elucidate this possibility.

Results of the present study indicate no significant relationships between Pe amplitudes and measures of empathy. This is consistent with previous research that suggests the Pe, unlike its error-related counterpart the ERN, is generally not related to affective or emotional variables (see Overbeek et al., 2005).

The precise neurocognitive mechanisms underlying the relationship between the ERN and empathy remain unclear. Santesso and Segalowitz (2008) postulate that the link between the ERN and empathy lies in the dopamine-mediated reinforcement learning theory of the ERN (Holroyd & Coles, 2002). According to this theory, the ERN is a reflection of a dopaminergic negative feedback reinforcement-learning signal produced when response outcomes are worse than expected. That is, when an unexpected error is committed, the dopamine system signals the occurrence of the unexpected event to trigger subsequent behavioral adjustments. This theory of ERN generation, coupled with additional work suggesting a link between the dopamine system and empathy (Abu-Akel, 2003) and socially-desirable response behaviors (Reeves et al., 2007), indicates a common underlying substrate of dopaminergic functions between the ERN and empathy. Poor dopamine regulation may, therefore, result in decreased empathy as well as decreased amplitude reinforcement-learning related ERN (Santesso & Segalowitz, 2008).

The current study should be considered in the context of several limitations. First, the sample included only healthy young adults. Empathy scores, therefore, tended to be relatively high. Increasing the range of empathy scores may strengthen the current findings. Next, our study utilized self-report ratings of empathy primarily from students at a religious institution. Empathic traits, in this context, would likely be considered desirable. Using self-report measures, therefore, opens up the possibility of a positive self-report bias. Comparison of ratings made by a significant other or close friend may have yielded interesting and potentially different results. Finally, our ERP averages consisted of a relatively low number of trials. We excluded all participants with fewer than seven usable error-trials; however, increasing the total number of trials would have likely resulted in more error trials and perhaps greater statistical and ERP reliability.

Summary and Conclusions

In conclusion, our findings provide further support for the hypothesis that empathy is related to error-processing neural mechanisms. Specifically, results indicate ERN amplitude was inversely related with measures of empathy, including overall empathic ability and the propensity to take the view of others in fictional situations. Results remained significant when partial correlations were used to control for measures of negative affect, and an additional relationship between ERN amplitude and level of empathic concern on the IRI emerged, potentially indicating a role of error-processing neural mechanisms in the regulation of negative affect. These results replicate and extend those of Santesso and Segalowitz (2008) in a more generalizable sample with more specific indices of empathy and error processing. Importantly, however, the unique individual relationships between the different components of empathy and ERN amplitude likely reflect a single underlying construct, as none of the empathy measures accounted for unique variance in ERN amplitude. Thus, it is likely the current study and that of Santesso and Segalowitz were picking up on a relationship between reflections of error processing and an underlying latent construct associated with empathy. Vigilance to the state of one's own performance and the emotional reactions of others is a potential construct underlying this relationship. Future research exploring the relationship between empathy, vigilance, and the neural correlates of both self-committed and observed errors would aid in understanding this possibility. Findings of the current study and those of Santesso and Segalowitz support a growing body of research suggesting ACC-mediated error-related mechanisms are multifaceted and include emotional/affective and cognitive constructs.

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