Psychophysiology, 53 (2016), 1143–1153. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/psyp.12671

Contextualizing individual differences in error monitoring: Links with impulsivity, negative affect, and conscientiousness

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Abstract

The error-related negativity (ERN) is a neural measure of error processing that has been implicated as a neurobehavioral trait and has transdiagnostic links with psychopathology. Few studies, however, have contextualized this traitlike component with regard to dimensions of personality that, as intermediate constructs, may aid in contextualizing links with psychopathology. Accordingly, the aim of this study was to examine the interrelationships between error monitoring and dimensions of personality within a large adult sample ($N = 208$). Building on previous research, we found that the ERN relates to a combination of negative affect, impulsivity, and conscientiousness. At low levels of conscientiousness, negative urgency (i.e., impulsivity in the context of negative affect) predicted an increased ERN; at high levels of conscientiousness, the effect of negative urgency was not significant. This relationship was driven specifically by the conscientiousness facets of competence, order, and deliberation. Links between personality measures and error positivity amplitude were weaker and nonsignificant. Post-error slowing was also related to conscientiousness, as well as a different facet of impulsivity: lack of perseverance. These findings suggest that, in the general population, error processing is modulated by the joint combination of negative affect, impulsivity, and conscientiousness (i.e., the profile across traits), perhaps more so than any one dimension alone. This work may inform future research concerning aberrant error processing in clinical populations.

Descriptors: Error processing, Individual differences, ERPs

The error-related negativity (ERN) is a negative deflection in the ERP waveform that occurs within 100 ms after the commission of an error on speeded tasks. This component is a neural marker of automatic error processing (Falkenstein, Hohnsbein, Hoorman, & Blanke, 1991; Gehring, Gross, Coles, Meyer, & Donchin, 1993) originating from the anterior cingulate cortex according to studies employing source localization (Dehaene, Posner, & Tucker, 1994; van Veen & Carter, 2002) and magnetoencephalography (Miltner et al., 2003) techniques. Functionally, the ERN is elicited when the mesencephalic dopamine system communicates to the anterior cingulate cortex that an error has been committed (Holroyd & Coles, 2002).

The ERN is of clinical interest due to its relationships with a wide range of psychopathological phenomena, forming a bipolar, transdiagnostic dimension of functioning (Olvet & Hajcack, 2008; Weinberg, Riesel, & Hajcak, 2012). In broad terms, individuals with internalizing symptoms—particularly generalized anxiety (Weinberg, Klein, & Hajcak, 2012; Weinberg, Kotov, & Proudfit, 2014; Weinberg, Olvet, & Hajcak, 2010) and obsessive compulsive disorders (Gehring, Himle, & Nisenson, 2000; Hajcak, Franklin, Foa, & Simons, 2008; Johannes et al., 2001; Riesel, Endrass, Auerbach, & Kathmann, 2015; Riesel, Kathmann, & Endrass, 2014; Ruchsow, Gron, et al., 2005)—tend to exhibit an enhanced ERN, while individuals with externalizing symptoms, such as substance abuse, tend to exhibit a blunted ERN (Franken, van Strien, Franzek, & van de Wetering, 2007; Hall, Bernat, & Patrick, 2007). ERN amplitude has been demonstrated to relate to negative affect broadly, with high negative affect potentiating the ERN and low negative affect attenuating the response (Hajcak, McDonald, & Simons, 2004). Moreover, specific symptoms have also been mapped onto ERN amplitude. For example, Weinberg and colleagues (2014) demonstrated that, in a patient sample with complex psychopathology, checking behaviors are associated with an enhanced ERN while psychomotor retardation is association with a blunted ERN. In light of these transdiagnostic findings, it has been proposed that not only does the ERN coactivate alongside defense systems in response to errors (Hajcak & Foti, 2008), but individual differences in ERN amplitude also track hypervigilance to threat (Jackson, Nelson, & Proudfit, 2014; Proudfit, Inzlicht, & Mennin, 2013; Weinberg, Riesel, & Hajcak, 2012). Consistent with this hypothesis, other research has found that the ERN reflects the dispositional salience of errors (Amodio, Master, Yee, & Taylor, 2008) and is sensitive to external motivational influences such as added incentives (Ganushchak & Schiller, 2008; Hajcak, Moser, Yeung, & Simons, 2005; Pailing & Segalowitz, 2004), punishment on errors (Endrass et al., 2010), emphasis on accuracy (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring et al., 1993), and

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performance evaluation (Hajcak et al., 2005). Notably, previous work has demonstrated that the effects of these external motivation manipulations may in turn be moderated by individual differences, suggesting interplay between trait- and context-level factors (Amodio et al., 2008; Chiu & Deldin, 2007; Dikman & Allen, 2000; Endrass et al., 2010; Pailing & Segalowitz, 2004).

Numerous studies have evaluated the ERN as a transdiagnostic dimension of psychopathological symptoms, and several have conceptualized it as a neurobehavioral trait (Patrick & Bernat, 2010) with robust temporal stability (Olvet & Hajcak, 2009; Segalowitz et al., 2010; Weinberg & Hajcak, 2011). However, few studies have explicitly contextualized this traitlike ERN with regard to a comprehensive model of general personality. This is an important next step in contextualizing the ERN, as characteristic patterns of personality functioning and psychological impairments overlap with each other in the real world. According to Widiger (2011), personality is related to psychopathology in three primary arenas: (1) personality and psychopathology are likely to mutually affect each other in presentation, (2) they share a spectrum relationship such that personality spans from normal to abnormal functioning with psychopathology residing at the extremes, and (3) they may share etiological relationships such that the presence of one characteristic has the capacity to contribute to the onset of another. There are numerous examples of these relationships, including high neuroticism being a robust predictor of psychopathological reactions to life stressors (Lahey, 2009; Malouff, Thorsteinsson, & Schutte, 2005; Widiger, 2009). Contextualizing dispositional characteristics and dimensional trait attributes has been described as a critical line of future research for utilizing neurobiological traits within a dimensional framework (Weinberg, Riesel, & Hajcak, 2012). The analysis of individual differences in error processing, and their relations to personality, may further our understanding of the dimensional framework through linking clinical phenomena to the general population.

Over the last 20 years, the field of personality has reached a consensus that human personality traits can be organized into five broad domains, known as the Big Five, or Five Factor Model (FFM; John, Naumann, & Soto, 2008). These broad domains are considered bipolar, in the sense that high and low standings are equally informative and represent conceptually opposite constructs, and so have been labeled neuroticism (vs. emotional stability), extraversion (vs. introversion), agreeableness (vs. antagonism), conscientiousness (vs. undependability), and intellect/openness (vs. closedness to new experiences). The FFM emerges across cultures (McCrae, Terracciano, & Pro, 2005) and has a great deal of empirical support including stability across the lifespan (Roberts, Walton, & Viechtbauer, 2006), robust relations with a variety of life outcomes (Ozer & Benet-Martinez, 2006) including psychopathology (Widiger & Trull, 2007), and even preliminary links with brain structure (DeYoung et al., 2010). These broad domains have also been divided up into individual traits that provide a more fine-grained assessment of personality. For example, one of the most prominent models was proposed by Costa & McCrae (1992) in their Revised NEO Personality Inventory (NEO PI-R). This model divides each of the five domains into six facets (i.e., 30 facets total) that provide more specificity in assessing the lower-order components. For instance, the domain of conscientiousness is subdivided into the facets of order, competence, dutifulness, achievement striving, self-discipline, and deliberation. Research has indicated that facets show specificity in their relations with various outcomes (Paunonen & Ashton, 2001), and so they may be particularly valuable to detecting links with relatively specific psychophysiological components, such as the ERN.

To explore the possibility of these relationships and neurobiological correlates, several studies have explored the relationship between the ERN and the FFM domains. Luu, Collins, and Tucker (2000) found that ERN amplitude was highly correlated with both state and trait negative affectivity (i.e., neuroticism). Moreover, progression through the task was also an important factor as individuals in the high trait negative affectivity group exhibited enhanced reactivity for the first 200 trials; however, as the task continued, their ERN responses diminished. In contrast, the low negative affectivity group showed the opposite pattern such that the ERN increased over the course of the task. Olvet and Hajcak (2012) built on these results in finding that not only does a sad mood induction lead to an enhanced ERN, but trait neuroticism also moderates this relationship. Specifically, individuals who reported higher levels of neuroticism exhibited a larger ERN if they reported a large increase in sadness after the mood induction, but not if they reported only a small increase in sadness; this relationship was not seen in individuals who reported low trait neuroticism. Taking the opposite approach, Larson, Good, and Fair (2010) demonstrated that satisfaction with life, a "positive personality" trait, is also related to the ERN above and beyond affect. Satisfaction with life seems to have a blunting effect on the ERN, leading researchers to conclude that ERN amplitude may not only reflect sensitivity to errors depending on personality characteristics (Potts, George, Martin, & Barratt, 2006), but also depending on current life circumstances or construal (Larson et al., 2010).

In a related line of research, Pailing and Segalowitz (2004) suggested that some people may be able to selectively invest in error monitoring, depending on the consequences of errors in the immediate context. These researchers found neuroticism and conscientiousness specifically to be important predictors of ERN amplitude. In their study, performance was differentially motivated across trials with monetary gains. The results conveyed an interesting interaction such that individuals in the low conscientiousness group displayed larger ERN responses when the monetary incentive was present; however, ERN responses did not differ for individuals in the high conscientiousness group across differing monetary incentive trials. These researchers found the opposite effect for neuroticism such that individuals high in neuroticism showed an enhanced ERN for monetarily rewarded trials. Further analyses demonstrated that neuroticism predicted a significant amount of the variance, above and beyond conscientiousness, in predicting this motivational effect on ERN amplitude.

These examinations of links between the ERN and personality have been quite useful for considering domain-level relations, but none have previously tested links with the FFM's lower-order facets. As noted above, the specificity of these facets makes them ideal candidates for isolating the potentially precise relations with ERP components. Some particularly compelling aspects would be the FFM facets that are tied to the overarching construct of impulsivity. Impulsivity is a personality characteristic that holds widespread clinical significance, perhaps second only to distressing symptoms as a diagnostic criterion across the mental disorders (Whiteside & Lynam, 2001). Along with an entire category for impulse-control disorders in the DSM-5 (American Psychiatric Association, 2013), impulsivity has been implicated as either a symptom or etiological factor for a variety of clinical outcomes including substance use (Sher, Bartholow, & Wood, 2000), gambling (Blasxcynski, Steel, & McConaghy, 1997), attention deficit hyperactivity disorder (Barkley, 1997), obsessive compulsive disorder (Bannon, Gonsalvez, Croft, & Boyce, 2002), borderline personality disorder (Crowell, Beauchaine, & Linehan, 2009), antisocial behaviors, and psychopathy (Newman & Wallace, 1993).

Despite its clinical significance, research on impulsivity has often been clouded by inconsistent operationalization. According to Block (1995), impulsivity is used as a blanket term for a variety of constructs including deficits in concentration, thrill-seeking tendencies, and disinhibition. Moreover, some previous impulsivity scales were conceptualized as measuring different factors of impulsivity that, in actuality, are inherently similar. Thus, impulsivity is actually a collection of more specific traits that have overlapping, but distinct nomological networks (Whiteside & Lynam, 2001). Within the FFM, impulsivity is primarily considered as part of low conscientiousness (i.e., facets of deliberation and self-discipline), but there are also aspects of the broad construct of impulsivity that fall within other domains (i.e., the facet of sensation seeking falls within extraversion and the facet of negative urgency falls within neuroticism). Building off of this framework, the UPPS-P impulsive behavior scale (Lynam, Smith, Whiteside, & Cyders, 2006; Whiteside & Lynam, 2001) is a comprehensive, empirically derived scale to measure the finer-grained constructs that fall under the broad rubric of impulsivity, or what has been termed *impulsogenic* traits.

The original four facets of the UPPS-P (including urgency, lack of premeditation, lack of perseverance, and sensation seeking) were arrived upon through the FFM theoretical framework, previous literature, and empirical support (Whiteside & Lynam, 2001); the fifth factor of positive urgency was later added in a revision (Lynam et al., 2006). The negative urgency factor measures the tendency to behave rashly during episodes of negative affect, whereas positive urgency indicates the tendency to conduct impulsive behaviors when in positive affective states. The (lack of) premeditation factor measures the tendency to plan before making decisions or taking action. The (lack of) perseverance factor measures the ability to work on a task until completion. Lastly, the sensation-seeking factor assesses chasing thrills or excitement (Whiteside & Lynam, 2001).

Two studies to date have explicitly studied the effect of impulsogenic traits on ERN amplitude; however, in each case impulsivity was measured as a singular construct rather than a constellation of distinct traits. Potts and colleagues (2006) found that individuals who reported impulsive tendencies had a smaller ERN on a flanker task when errors were punished than did individuals who reported low impulsive tendencies. The analyses conducted in this study used a median split on the Barratt Impulsiveness Scale to determine high-impulsive and low-impulsive groups. Secondly, Ruchsow, Spitzer et al. (2005) again found that individuals with higher impulsivity exhibited smaller ERN amplitudes. In this study, impulsivity was also determined according to a median split measure of impulsivity, in this case of participants' reaction times. Individuals who responded to task stimuli more quickly were determined to be impulsive due to their "less controlled" response style. These studies suggest that impulsivity—broadly defined—is related to blunted sensitivity to errors, which is consistent with other research in externalizing psychopathology.

Following the ERN, the error positivity (Pe) is a positive slow wave in the ERP waveform that is maximal approximately 200–400 ms post-error at centroparietal sites (Falkenstein et al., 2000; Hohnsbein, Falkenstein, & Hoormann, 1989). Although the Pe has been far less studied than the ERN, it is thought to reflect a later stage of error processing, perhaps the conscious awareness of having made an error (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Furthermore, it has been shown to have distinct patterns with psychopathology symptoms from those demonstrated with the ERN. For example, high negative affect relates to a blunted Pe (Hajcak et al., 2004), as does anxious apprehension (Moser, Moran, & Jendrusina, 2012), whereas these factors potentiate the ERN.

While few studies have evaluated the ERN in relation to personality traits, even fewer have evaluated the Pe in relation to these dimensions. Of the studies discussed, a majority either did not mention the Pe (Pailing & Segalowitz, 2004; Potts et al., 2006) or reported observing the Pe, but did not explore the Pe in relation to personality factors (Luu et al., 2000; Olvet & Hajcak, 2012). Two studies, however, did include such analyses. Larson and colleagues (2010) did not find any significant relationships, and Ruchsow, Spitzer et al. (2005) observed an enhanced Pe within the low impulsivity group, but only during an early time window (0–250 ms). This study indicates that relationships among the Pe and personality domains may differ from relationships documented among the ERN and these domains; however, this topic has been largely unexplored in previous literature. Assessing these differences has the potential to expand our understanding of personality profiles and error processing. Should the Pe and ERN share the same relationships with personality traits, it is perhaps general error processing that relates to the constructed personality profiles; however, if these separate components of error processing differentially relate to personality traits, that would suggest stage-specific (ERN vs. Pe) personality profiles, rather than error processing generally.

Taken together, studies to date have established tentative links between the ERN and relevant personality dimensions, particularly neuroticism, conscientiousness, and impulsivity. Several important gaps, however, remain: (a) studies have not systematically assessed the FFM and impulsivity together using comprehensive measures, (b) studies to date have been underpowered to detect correlations with personality traits (N range = 18–54), (c) whereas several studies have examined the ERN in relation to personality, the Pe has been largely neglected, (d) it has been demonstrated that impulsivity is generally related to a blunted ERN (Potts et al., 2006; Ruchsow, Spitzer, Grön, Grothe, & Kiefer, 2005), yet it is not yet known which facets of impulsivity exhibit this relationship, and (e) furthermore, the ERN has been related to personality traits from the FFM (Luu et al., 2000; Olvet & Hajcak, 2012; Pailing & Segalowitz, 2004), yet no study to date has comprehensively measured personality profiles in relation to the ERN or Pe. The present study aims to answer these questions through the utilization of two validated personality measures, the UPPS-P impulsive behavioral scale and Five Factor Model Rating Form (FFMRF), within a large, representative adult sample.

Furthermore, we aim to build on the previously found additive effects of personality (e.g., high conscientiousness relates to a larger ERN) by also considering potential multiplicative effects by testing for interactions between personality dimensions in relating to ERN/Pe amplitudes (e.g., Does the relationship between conscientiousness and the ERN depend on neuroticism?). In this way, not only can we support that the ERN/Pe relate to several personality traits, but we also can discover specific personality profiles for these ERPs (i.e., relevant combinations of traits, or profiles). This reflects a previous call for research that will relate a neurobehavioral trait to dimensions of personality (Weinberg, Riesel, & Hajcak, 2012).

Method

Participants

Two hundred and sixty-four adults participated in this study. Twenty-four subjects (9.1%) were removed from data analyses due

Table 1. *Descriptive Statistics (Mean, SD) and Internal Consistency (Cronbach's alpha) for the FFMRF Domains and UPPS-P Facets*

	Mean (*SD*)	α
FFMRF		
Neuroticism versus emotional stability	11.32 (3.73)	.75
Extraversion versus introversion	20.99 (4.10)	.76
Openness versus closedness to one's own experience	21.03 (3.94)	.70
Agreeableness versus antagonism	21.57 (3.60)	.69
Conscientiousness versus undependability	22.89 (3.86)	.81
UPPS-P		
Negative urgency	27.22 (5.54)	.79
(Lack of) premeditation	21.63 (4.28)	.75
(Lack of) perseverance	17.62 (4.62)	.84
Sensation seeking	34.25 (6.43)	.83
Positive urgency	29.81 (6.15)	.82

Note. A total of 210 participants were included in the analysis of the FFMRF. A total of 239 participants were included in the analysis of the UPPS-P.

to committing too few errors (≤ 5; $n = 8$), poor performance on the task (less than 75% correct; $n = 10$), or ERN or Pe scores that were statistical outliers (5 standard deviations from the mean; $n = 6$). This left 242 participants with available ERP and behavioral data. Participants were between the ages of 18 and 72 ($M = 22.75$; $SD = 8.47$). A majority of participants were White ($n = 171$), with a relatively small number of participants identifying as African American ($n = 12$), Asian ($n = 53$), Native American ($n = 2$), and biracial ($n = 1$); three participants did not identify. A small number of participants identified as Hispanic ($n = 10$). The sample consisted of 142 females, 96 males, and 4 individuals who did not identify. A subset of the sample was not administered the FFMRF ($n = 32$), leaving 208 participants for the personality analyses after accounting for missing demographic data. Participation was voluntary, with either extra credit for a psychology course or $20 as compensation. This research was formally approved by the Purdue University Institutional Review Board.

Measures

FFMRF. The FFMRF (Mullins-Sweatt, Jamerson, Samuel, Olson, & Widiger, 2006) is a 30-item scale designed to assess the five personality domains (neuroticism, extraversion, openness, conscientiousness, agreeableness) and 30 corresponding personality facets (six per domain) from the FFM (Costa & McCrae, 1992). The domain of neuroticism is composed of anxiousness, angry hostility, depressiveness, self-consciousness, impulsivity, and vulnerability facets. The conscientiousness domain consists of competence, order, dutifulness, achievement, self-discipline, and deliberation. Items are rated on a Likert-type scale ranging from 1–5 with exemplars for each anchor. For example, the anxiousness item of the neuroticism domain ranges from 1 (*fearful, apprehensive*) to 5 (*relaxed, unconcerned, cool*), and the competence item of the conscientiousness domain ranges from 1 (*perfectionistic, efficient*) to 5 (*lax, negligent*). The FFMRF has been demonstrated to have strong internal consistency, convergent validity, and discriminant validity (Mullins-Sweatt et al., 2006; Samuel, Mullins-Sweatt, & Widiger, 2013). In the current sample, the internal consistency statistic Cronbach's alpha ranged from $\alpha = .69$ (agreeableness) to $\alpha = .81$ (conscientiousness; Table 1).

UPPS-P. The UPPS-P (Lynam et al., 2006) is a 59-item scale designed to assess the five impulsogenic facets within the FFM framework. These facets include: positive urgency, negative urgency, lack of perseverance, lack of premeditation, and sensation seeking. Items are rated on a Likert-type scale ranging from 1 (*agree strongly*) to 4 (*disagree strongly*). The UPPS-P has been well validated in clinical populations and has strong internal consistency (Cyders et al., 2007; Whiteside & Lynam, 2001; Whiteside, Lynam, Miller, & Reynolds, 2005). In the current sample, the internal consistency statistic Cronbach's alpha ranged from $\alpha = .79$ (negative urgency) to $\alpha = .84$ (lack of perseverance; Table 1).

Laboratory Task

Error-related ERPs were elicited using an arrow flankers task (Eriksen & Eriksen, 1974). On each trial, five arrows were presented in the center of the screen for 200 ms and were followed by an intertrial interval that varied randomly from 2,300 to 2,800 ms. Presentation software (Neurobehavioral Systems, Inc., Berkeley, CA) was used to control the timing and presentation of all stimuli. Participants were instructed to attend to the center arrow among the array of five, and to respond with a right click if the center arrow was pointing right and a left click if the center arrow was pointing left. There were both congruent trials, when all five arrows pointed in the same direction (>>>>> or <<<<<), and incongruent trials, when the flanking arrows (two on each side of the center) pointed in the opposing direction of the center arrow (>><>> or <<><<). Feedback was provided blockwise throughout the task instructing the participant to respond more quickly (for performance > 90%), to respond more accurately (for performance < 75%), or to keep repeating the same behavior. This task had a practice block of 15 trials; the main task was 300 trials broken into 10 blocks, and took approximately 12 min. Participants had a self-paced break after each block.

Psychophysiological Recording and Data Reduction

To record the continuous EEG, each participant was fitted with a 32-electrode cap (actiCAP), oriented on the International 10/20 system. The continuous EEG data were recorded through actiCHamp amplifer (Brain Products GmbH, Munich, Germany). The EEG signal was digitized at 24-bit resolution, with a 500 Hz sampling rate. The electrooculogram was recorded from two auxiliary electrodes placed 1 cm above and below the left eye, forming a bipolar channel. The impedance at each electrode site was kept below 30 kOhm. Once the EEG data were collected, it was processed offline using BrainVision Analyzer software (Brain Products). First, the signal from each electrode was referenced to the average of the mastoid electrodes. The data were then filtered to eliminate skin conductance and muscle activity interference using a band-pass filter of .1 Hz to 30 Hz. Next, the data were segmented in order to isolate the time that we were interested in, specifically −400 ms to 800 ms around the participant's response in order to capture the ERN/Pe. In order to remove any eyeblinks that coincide with the desired signal, the signal gathered from the eye electrode sites was used for ocular correction (Gratton, Coles, & Donchin, 1983). Individual channels were rejected trialwise for artifacts using a semiautomated procedure. Segments were averaged separately for correct and error trials. The ERN was scored as the average activity from 0–100 ms postresponse at a pooling of Fz, Cz, FC1, and FC2. The Pe was scored as the average from 200–400 ms at Cz, CP1, CP2, and Pz. Lastly, these poolings were compared to

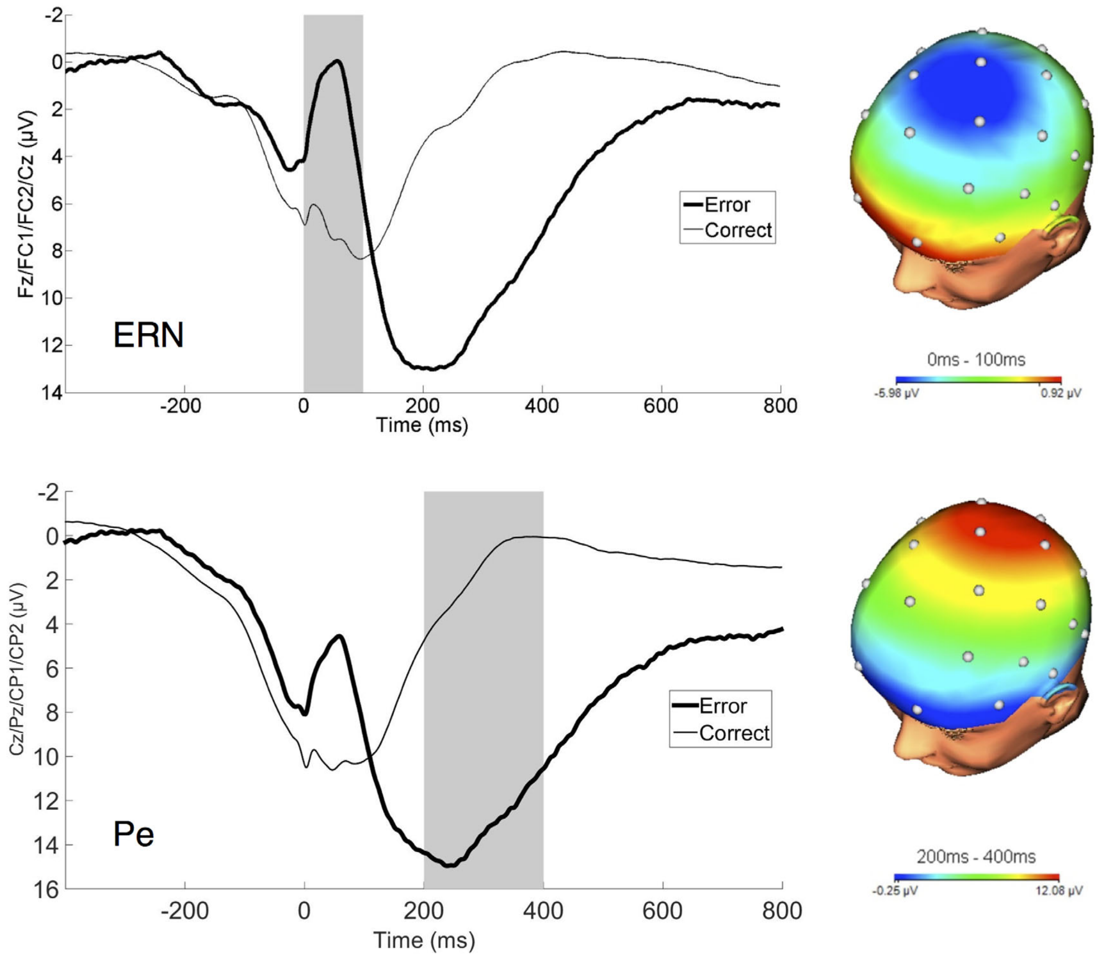

Figure 1. ERP results depicting the error-related negativity (ERN, top) and error positivity (Pe, bottom). Negative is plotted up. The graph on the top left depicts response-locked ERPs for error and correct trials. The illustration to the top right conveys the scalp topography of the ERN at 0–00 ms postresponse; response onset occurred at 0 ms. The graph on the bottom left depicts response-locked ERPs for error and correct trials. The illustration on the bottom right conveys the scalp topography of the Pe at 200–400 ms post response; response onset occurred at 0 ms.

the baseline of each participant −400 ms to −200 ms preresponse. A difference wave, created by subtracting ERPs on correct trials from ERPs on error trials, was calculated to isolate error processing for both the ERN and Pe.

Procedure

Upon entering the lab, participants were given the informed consent protocol, with adequate time for questions. Next, they completed the flankers task while continuous EEG data were recorded. They then completed a battery of self-report personality assessments including the UPPS-P and FFMRF. Afterward, participants were fully debriefed and compensated.

Data Analysis

Behavior and ERP data were statistically evaluated using SPSS General Linear Model software (Version 22; SPSS Inc., Chicago, IL). Paired sampled *t* tests were used with ERP and behavioral data to document the differences between correct and error trials. The Pearson correlation coefficient (r) was used to examine bivariate relationships between ERPs, behavioral data, and personality facets.

Multiple regression analyses were used to examine the ability of scores from the FFMRF and the UPPS-P to uniquely, or in combination, predict ERN and Pe amplitudes. Solely neuroticism and conscientiousness were evaluated from the FFM, in line with previous research demonstrating relationships between these domains and the ERN (Hajcak et al., 2004; Pailing & Segalowitz, 2004); all five UPPS facets were considered, insofar as the specific relationships with error processing are not clear from previous studies. Hierarchical regression was used to determine the significance of interactions among these personality variables in predicting the ERN/Pe. For these analyses, independent predictors were first centered by subtracting the mean of each variable from every individual data point. Then, an interaction term was created by multiplying the centered variables of interest. Each of these variables was then entered into the regression model. In Step 1, the component of interest (e.g., ERN) was regressed onto demographic variables (age, gender, race, ethnicity), and behavioral performance (percent correct). In Step 2, main effects of personality traits were added to the model (e.g., conscientiousness, sensation seeking). Finally, in Step 3, the relevant multiplicative term of interest was added (e.g., Conscientiousness × Sensation Seeking).

Significant interactions were probed using this hierarchical regression model at high (+1 standard deviation) and low (−1

Table 2. *Bivariate Correlations*

	% correct	RT (error)	RT (correct)	Post-error slowing	ΔERN	ΔPe
Negative urgency	−.02	.05	.03	.01	−.03	.01
Positive urgency	−.04	−.02	−.07	−.02	−.01	−.02
Lack of premeditation	−.16*	−.08	−.09	.00	−.01	.07
Lack of perseverance	−.16*	−.06	−.06	−.17**	−.05	.08
Sensation seeking	−.10	−.12	−.14*	.00	−.02	−.02
Neuroticism	−.06	.00	.01	.00	−.03	.04
Anxiousness	.02	.06	.05	.02	−.05	−.08
Angry hostility	.03	.07	.08	.04	−.02	.08
Depressiveness	−.01	−.02	.04	−.01	−.08	.04
Self-consciousness	−.08	−.06	−.07	.01	.00	.07
Impulsivity	−.06	−.03	−.02	.00	.02	.04
Vulnerability	−.13	−.03	−.03	−.05	.03	.02
Extraversion	.02	.02	−.02	.00	.11	.13
Openness	−.04	−.04	−.04	−.04	.01	.02
Agreeableness	.02	.05	.03	.11	.06	.09
Conscientiousness	.12	.14*	.13	.14*	.08	−.02
Competence	.05	.08	.10	.03	.06	−.04
Order	.06	.12*	.13	.10	.04	.02
Dutifulness	.07	.04	.05	.12	.04	.00
Achievement	.16*	.16*	.12	.20**	.07	.03
Self-discipline	.13	.11	.09	.17*	.08	−.04
Deliberation	.07	.09	.06	.00	.06	−.03
Age	.25**	.16*	.18**	.05	−.05	−.07

Note. A total of 208 participants were included in this analysis. Post-error slowing is the difference between correct trials following error trials and correct trials following correct trials. ERP variables are the difference between error and correct trials.
$*p < .05$. $**p < .01$.

standard deviation) values of the moderating predictor variable. Slopes were constructed using these transformations of each specific data point, rather than dichotomizing the variables, in order to maintain variability and thus power to detect these relationships. In the example conveyed throughout the previous paragraph, this simple slopes analysis would consist of three steps: (1) selecting the moderating variable (conscientiousness), (2) recentering the individual data points of this variable such that they now represent either high (+1 *SD*; very conscientious) or low (−1 *SD*; not very conscientious) values of the moderating variable, and (3) rerunning the regression analysis with Step 1 controlling for demographics and behavioral data, Step 2 including sensation seeking (centered around the mean) and conscientiousness (centered at 1 *SD* above the mean), and Step 3 including the multiplicative term: Sensation Seeking × high levels of Conscientiousness. This procedure probes interactions by allowing the researcher to determine whether the predictor variable (sensation seeking) has the greatest relationship with the outcome variable (ERN) at low (−1 *SD*), medium (mean centered), or high (+1 *SD*) levels of conscientiousness (Cohen, Cohen, West, & Aiken, 2013).

Significant results were also subjected to split-half analyses in order to determine the replicability of effects. In order to conduct these analyses, subjects were first randomly assigned to two groups. This step allows for the unbiased comparison of these two unrelated groups. After splitting the data, we again ran the hierarchical regression models described above. Each half displaying the same pattern of results conveys greater evidence that significant findings were not spurious.

Results

Within-Subject Analyses

Behavioral data. On average, participants were correct on 89.20% of trials (number of errors $M = 32.40$; error $SD = 13.65$). Mean reaction time was faster on error trials ($M = 474.61$ ms; $SD = 56.20$) versus correct trials ($M = 580.33$ ms; $SD = 66.15$), $t(241) = -38.79$, $p < .001$. Mean reaction time on correct trials following a correct response was significantly faster than on correct trials following an erroneous response, $t(241) = -10.51$, $p < .001$, indicating significant post-error slowing (PES).

ERPs. The ERN was significantly more negative than the correct error negativity (CRN; $t(241) = 22.64$, $p < .001$). Figure 1 presents the grand-averaged ERP waveforms for correct and error trials at a pooling of the electrode sites Fz, FC1, FC2, and Cz. The ERN is apparent as the negative deflection peaking at approximately 50 ms after an incorrect response. In the illustration on the right, Figure 1 also presents the scalp topography of the difference in ERPs between error and correct trials in the 0 to 100 ms window following responses.

The error positivity (Pe) was significantly more positive than the correct positivity, $t(241) = -33.02$, $p < .001$. Figure 1 presents the grand-averaged ERP waveforms for correct and error trials at a pooling of the electrode sites Cz, Pz, CP1, and CP2. The Pe is apparent as the positive deflection peaking at approximately 250 ms after an incorrect response. In the illustration on the right, Figure 1 also presents the scalp topography of the difference in ERPs between error and correct trials in the 200 to 400 ms window following responses.

Between-Subjects Analyses

Bivariate correlations. Correct trial reaction time, error trial reaction time, and post-error slowing behavioral performance measures shared several small, significant correlations with personality traits (Table 2). FFMRF conscientiousness was associated with greater post-error slowing, whereas the UPPS-P lack of perseverance facet was associated with less post-error slowing. Conscientiousness was also associated with greater reaction time on error trials. Lastly,

Table 3. *Hierarchical Regression Predicting ERN Difference Amplitude*

Variable	*B*	*SE (B)*	*β*	*t*	*p*	ΔR^2
Step 1						
Demographic information						
% correct						
						.02
Step 2						
Conscientiousness	.07	.07	.07	.98	.33	
Negative urgency	−.06	.50	−.01	−.12	.91	
						.00
Step 3						
Cons × NU	.31	.14	.16	2.27	.03*	
						.02*
Step 4						
Cons × NU	.30	.14	.16	2.25	.03*	
Neuroticism	−.04	.08	−.03	−.43	.67	
						.00

Note. Demographic information in Step 1 of the model included age, gender, and race/ethnicity. Step 4 was added to the model in order to demonstrate the effects of conscientiousness and negative urgency above and beyond general neuroticism. Here, neuroticism is composed of the anxiousness, angry hostility, depressiveness, self-consciousness, and vulnerability facets, but not the impulsivity facet. A total of 208 participants were included in this analysis. Cons = conscientiousness; NU = -negative urgency.
*$p < .05$. **$p < .01$.

UPPS-P sensation seeking was negatively associated with reaction time on correct trials. Age was associated with greater percent correct and greater reaction time on both correct and error trials. Women had greater reaction time on correct trials than men, $t(236) = -2.25$, $p < .05$. The relationship between race/ethnicity and outcome variables was evaluated by first coding the data into three groups: non-Hispanic White, Asian, and minority group participants. No significant relationships emerged, all *ps* > .05. Lastly, no single personality variable related to ERN difference or Pe difference amplitude at the bivariate level.

Behavioral measures in relation to personality. To assess the predictive ability of personality on behavior, we conducted two multiple regressions. First, post-error slowing was regressed onto the UPPS-P facets. The overall model was not significant, $F(5,233) = 2.00$, $p = .081$; $R^2 = .04$, but the unique effect of lack of perseverance remained significant, as in the bivariate analyses, $\beta = -.23$; $sr^2 = 3.96\%$, $p = .002$. Secondly, post-error slowing was regressed onto the FFMRF personality facets. The overall model did not significantly predict post-error slowing, $F(5,204) = 1.39$, $p > .05$; $R^2 = .03$; however, conscientiousness continued to exhibit the largest effect, $\beta = .14$; $sr^2 = 1.66\%$, $p = .062$.

ERPs in relation to personality. Based on previous literature linking the ERN (error minus correct) to conscientiousness and neuroticism, we explored interactions between these two personality domains and the UPPS-P facets. To explore these interactions, we ran 10 separate regression analyses. The first five models regressed ERN amplitude onto the multiplicative terms for neuroticism and each of the UPPS-P facets, controlling for demographics, percent correct, and main effects (i.e., neuroticism, negative urgency, positive urgency, lack of premeditation, lack of perseverance, and sensation seeking). Each of these models was nonsignificant, $p = .09$–$.53$.[1] The second five models regressed ERN amplitude onto the multiplicative terms for conscientiousness and each of the UPPS-P facets, while again including demographics, percent correct, and the corresponding main effects (i.e., conscientiousness, negative urgency, positive urgency, lack of premeditation, lack of perseverance, and sensation seeking). The interaction between conscientiousness and negative urgency was found to be a significant predictor of ERN amplitude ($\beta = .16$; $\Delta R^2 = 2.4\%$, $p = .025$),[2] indicating that the interaction between the domain of conscientiousness and the specific facet of negative urgency accounted for 2.40% of the variance above and beyond demographic information, percent correct, and the main effects of conscientiousness and negative urgency. This effect remained significant even when controlling for overall neuroticism uniquely captured by the FFMRF (i.e., removing the facet of impulsivity that is captured by the UPPS-P as negative urgency), suggesting that it is specific to negative urgency and is not a product of negative affectivity broadly (Table 3).

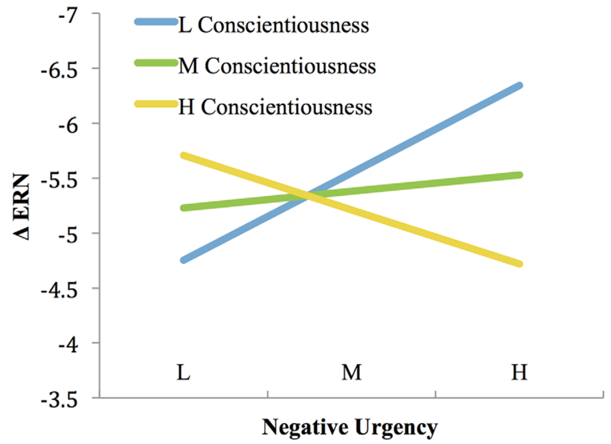

Figure 2. The interaction between conscientiousness and negative urgency predicting ERN difference amplitude. Negative is plotted up. Slopes were constructed using low (−1 *SD*), medium (+0), and high (+1 *SD*) transformations of each data point for both conscientiousness and negative urgency. As demonstrated, at lower levels of conscientiousness, negative urgency predicts a larger (more negative) ERN.

In order to probe this interaction,[3] the ERN was regressed onto negative urgency and high, low, and medium levels of conscientiousness (+1 *SD*, −1 *SD*, and +0 *SD*, respectively). This simple slopes analysis evaluated where the predictive relationship was strongest along the moderating variable (i.e., conscientiousness). Furthermore, this analysis maintained the continuity of values rather than dichotomizing them, thus allowing for the comparison of slopes rather than groups. Using this technique, we found that, at lower levels of conscientiousness, negative urgency significantly predicted a larger (more negative) ERN ($\beta = -.22$, $t(197) = -2.04$, $p = .045$). At high and medium levels of conscientiousness, negative urgency

1. These nonsignificant results were maintained when including only unique aspects of neuroticism (i.e., facets not captured by the UPPS-P: anxiousness, angry hostility, depressiveness, self-consciousness, and vulnerability) in the model.

2. This pattern (i.e., negative urgency being the only UPPS-P facet that significantly interacted with conscientiousness) was maintained when including only unique aspects of conscientiousness (facets not captured by the UPPS-P: competence, order, dutifulness, and achievement) in the model.

3. There was a small negative correlation between negative urgency and conscientiousness, $r = -.22$, $p = 001$.

Table 4. *Hierarchical Regression Predicting the ERN from Facets of Conscientiousness*

Variable	B	SE (B)	β	t	p	ΔR^2
Step 1						
Demographic information % correct						
Step 2						
Main effects						
Step 3						
Competence × NU	1.17	.53	.16	2.20	.03*	.023*
Order × NU	1.12	.49	.16	2.31	.02*	.025*
Dutifulness × NU	.59	.63	.07	.93	.35	.004
Achievement × NU	.85	.55	.11	1.55	.12	.012
Self-discipline × NU	.77	.57	.10	1.34	.18	.009
Deliberation × NU	1.38	.58	.17	2.39	.02*	.027*

Note. Demographic information in Step 1 of analysis included age, gender, and race/ethnicity. Main effects included in Step 2 of analysis were dependent on the multiplicative term being assessed for the model. Specifically, the main effects of competence and negative urgency were used for Model 1, order and negative urgency for Model 2, dutifulness and negative urgency for Model 3, achievement and negative urgency for Model 4, self-discipline and negative urgency for Model 5, and deliberation and negative urgency for Model 6. A total of 208 participants were included in this analysis. NU = negative urgency.
$^*p < .05$. $^{**}p < .01$.

was not a significant predictor of ERN amplitude, $\beta = .14$ and $\beta = -.04$, respectively; $p > .05$ (Figure 2).

Due to the statistically significant, yet small, nature of these findings, we pursued their replicability through a split-half analysis of the data. Subjects were randomly split into two groups with 117 and 125 subjects in each group due to the nature of random assignment. In each case, conscientiousness and negative urgency interacted to predict ERN amplitude. The split-half analyses indicated equivocal effect sizes across the randomly selected halves of the sample, $\beta = .22$, $t(108) = 2.02$, $p < .05$; $\beta = .21$, $t(116) = 2.00$, $p < .05$.

A strength of the FFMRF is its robustness at both the domain and facet level. For this reason, we were able to further analyze the interaction of conscientiousness by negative urgency by deconstructing conscientiousness into its constituent facets. Using the same hierarchical regression model as described above, we evaluated which facets of conscientiousness interacted with negative urgency to predict the ERN. Three of the six conscientiousness facets, competence ($\beta = .16$, $p < .05$), order ($\beta = .16$, $p < .05$), and deliberation ($\beta = .17$, $p < .05$), significantly predicted the ERN (similar to the domain-level effect of conscientiousness), while dutifulness, achievement, and self-discipline did not, $\beta\text{s} < .11$, $p\text{s} > .12$ (Table 4).

Parallel with these ERN analyses, we calculated the analogous regression models predicting Pe amplitude. Negative urgency and conscientiousness were again found to be relatively important predictors, as their interaction trended towards significance, $\beta = .12$, $\Delta R^2 = .01$, $t(202) = 1.73$, $p = .086$; no other effects were statistically significant.

Discussion

The overarching aim of this study was to begin to bridge the gap between personality and error monitoring using a large community sample. Consistent with previous research, we demonstrated that conscientiousness broadly and specific traits that fall under the broad term of impulsivity are important to understanding behavioral and psychophysiological measures related to error monitoring. Psychophysiological links with personality were relatively specific to the ERN; links with the Pe were weaker and nonsignificant. Personality factors also demonstrated specificity, as more narrow facets of these constructs related to post-error slowing and drove the multiplicative relationship predicting the ERN. Contrary to previous research, we were unable to find straightforward relationships between the ERN and neuroticism.

There are several possible reasons for this discrepancy, including principal differences in study design. Olvet and Hajcak (2012) employed the Big Five Inventory (BFI; John & Srivastava, 1999) to measure trait neuroticism and found that this entity moderated a relationship between negative affect after a mood induction and ERN amplitude. Pailing and Segalowitz (2004) used the International Personality Item Pool (IPIP; Goldberg, 1999) to assess neuroticism and found that neuroticism had a special relationship with ERN amplitude when considering differences in motivation across monetary incentives. Together, these studies suggest that the relationship between neuroticism and the ERN is dependent on several factors including motivation and mood.

While our results did not find a relationship between ERN amplitude and neuroticism directly, we did find a specific relationship between ERN amplitude and the trait of negative urgency. As described by Whiteside and colleagues (2005), negative urgency falls under the domain of neuroticism. Neuroticism broadly is a person's tendency to experience negative affect, and thus negative urgency is conceptually linked with the impulsivity facet of neuroticism[4] (Kaiser, Millich, Lynam, & Charnigo, 2012). This idea was supported by Whiteside and Lynam (2001) when an exploratory factor analysis found four factors relating to impulsivity within the FFM framework. The second of these factors, urgency, included the NEO-PI-R's facet of impulsiveness.

Moreover, negative urgency was the only facet of impulsivity found to have a relationship with ERN amplitude. Specifically, at low levels of conscientiousness, increased negative urgency potentiated the response. This finding is contrary to previous work finding that a total impulsivity score relates to a blunted ERN (Potts et al., 2006; Ruchsow, Spitzer et al., 2005); however, it supports previous work finding that negative affect relates to an enhanced ERN (Hajcak et al., 2004). Moreover, this result further exemplifies that this relationship is also dependent upon contextual factors, such as length of task (Luu et al., 2000). The previous studies of impulsivity divided participants into high and low impulsivity groups thus removing the possibility of exploring linear relationships. By retaining this information, we were able to discover the additional nuance of when negative urgency seems to have the most predictive power—at low levels of conscientiousness.

Conscientiousness and negative urgency appear to interact to produce the greatest predictive power of ERN amplitude, rather than have direct effects. With this knowledge, we are closer to building personality and, relatedly, psychopathology profiles that relate to neurobehavioral traits. Future research should seek to determine what this personality profile looks like for behaviors and future outcomes. There is already a plethora of research relating negative urgency to psychopathology (Settles et al., 2012) and conscientiousness to psychopathology (Roberts, Jackson, Burger, & Trautwein, 2009); however, determining how these constructs

4. In our data, these constructs (UPPS-P negative urgency and FFMRF impulsivity facet of neuroticism) shared a moderate correlation, $r = .36$, $p < .001$.

interact, and the ERN's role insofar as predictive power, will be important next steps in this line of research.

Incorporating these results with the previous literature, it seems that high levels of conscientiousness relate to an enhanced ERN in a relatively fixed manner, but that at low levels of conscientiousness, ERN amplitude is more malleable and sensitive to negative urgency. This modulation could be due to manipulation of the task. For example, Pailing and Segalowitz (2004) found that the addition of monetary rewards to the experimental task resulted in an increased ERN for individuals low in conscientiousness, but did not affect the ERN for individuals high in conscientiousness. However, it also seems this modulation is not specific to experimental manipulation and rather is also affected by individuals' own affect regulation style. This is exemplified through negative urgency's effect in predicting the ERN only at low levels of conscientiousness. This study employed a simple flankers task without motivational manipulations; using such tasks in future studies may exacerbate the effects found here.

While the effect sizes found here are relatively small (all βs $<$ .18), it is important to remember several factors. First, as alluded to above, the flankers task used in this study did not punish or reward responses. Previous work has demonstrated such feedback to be important in detecting certain individual differences. Specifically, Dikman and Allen (2000) found that a difference in ERN amplitude between high- and low-socialized individuals was only seen when erroneous responses were punished. Secondly, the FFMRF was developed as a brief assessment tool and thus is not as powerful as other longer measures, such as the IPIP-NEO (Goldberg, 1999) or the BFI (John & Srivastava, 1999) in terms of robust domain estimates. Lastly, small effects are often the nature of multimethod assessment due to method-specific variance (e.g., Cyders & Coskunpinar, 2011). Nonetheless, Type I error is a concern given the large sample employed in our study and the size of the effects. Rather than use a traditional Bonferonni correction, we used split-half analyses to replicate these effects within our own data. Addressing Type I error concerns in this way is conceptually different than the Bonferonni correction. While the Bonferroni approach restricts significant effects to those that meet a minimal threshold, and thus small though significant effects may disappear, split-half analyses only pertain to the consistency of effects such that small effects may survive as long as they are replicable. Conceptually, in each half of the dataset, we found the interactive relationship of conscientiousness and negative urgency in predicting the ERN. Here, we contextualized the ERN in relation to personality, building off of previous work relating the ERN to clinical phenomena (for a review, see Olvet & Hajcak, 2008) and specific behaviors (Weinberg et al., 2014). A future direction for this line of research will be seeing if other laboratories replicate these findings.

Concerning both clinical phenomena and specific behaviors, Weinberg and colleagues (2014) found that a larger ERN related specifically to clinical checking behaviors in a diverse clinical sample of patients with diagnoses of generalized anxiety disorder, obsessive-compulsive disorder, major depressive disorder, and comorbid presentation of the three. While repetitive behaviors (e.g., checking) is a specific symptom of obsessive-compulsive disorder, this behavior seems inherently related to the facets of conscientiousness that drive the relationship between negative urgency and the ERN demonstrated in the present study: competence, order, and deliberation. A future analysis including psychophysiological, behavioral, and personality measures would properly assess this hypothesis.

Along with psychophysiological measures of error monitoring, behavioral performance also demonstrated several significant relationships with the domain of conscientiousness as well as specific impulsogenic traits. Post-error slowing significantly correlated with the UPPS-P facet of lack of perseverance and the FFMRF conscientiousness facets of achievement and self-discipline. These relationships are significant in that they demonstrate replicability across measures. As explained by Whiteside and Lynam (2001), the UPPS-P facet of lack of perseverance is derived from the FFM facet of self-discipline.

In conclusion, this study demonstrates that interrelationships between error monitoring and personality traits may be more complex than previously thought. Within the domain of conscientiousness, specific facets (competence, order, and deliberation) appear to be most relevant with regard to error processing. Further, the blunting of the ERN is not linked to all impulsogenic traits broadly, but rather is more specific to the effects of one specific facet—negative urgency—that has its origins in the domain of neuroticism. Moreover, while conscientiousness and specific traits that fall under the umbrella of impulsivity relate to the ERN, as demonstrated here and in previous projects, negative affect plays a role, too. In fact, these constructs interact with one another in their relationships with ERN amplitude, yielding a more nuanced understanding of individual differences in error processing within the general population. This work is integral to future research concerning clinical populations, as well as understanding personality-psychopathology relationships across this psychophysiological dimension.

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(Received November 17, 2015; Accepted April 8, 2016)