Published in final edited form as:

Biol Psychol. 2013 April ; 93(1): 225–230. doi:10.1016/j.biopsycho.2013.02.010.

Error-Related Brain Activity in Extraverts: Evidence for Altered Response Monitoring in Social Context

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Abstract

While the personality trait of extraversion has been linked to enhanced reward sensitivity and its putative neural correlates, little is known about whether extraverts' neural circuits are particularly sensitive to social rewards, given their preference for social engagement and social interactions. Using event-related potentials (ERPs), this study examined the relationship between the variation on the extraversion spectrum and a feedback-related ERP component (the error-related negativity or ERN) known to be sensitive to the value placed on errors and reward. Participants completed a forced-choice task, in which either rewarding or punitive feedback regarding their performance was provided, through either social (facial expressions) or non-social (verbal written) mode. The ERNs elicited by error trials in the social – but not in non-social – blocks were found to be associated with the extent of one's extraversion. However, the directionality of the effect was in contrast with the original prediction: namely, extraverts exhibited smaller ERNs than introverts during social blocks, whereas all participants produced similar ERNs in the non-social, verbal feedback condition. This finding suggests that extraverts exhibit diminished engagement in response monitoring – or find errors to be less salient – in the context of social feedback, perhaps because they find social contexts more predictable and thus more pleasant and less anxiety provoking.

Keywords

extraversion; event-related potentials; error-related negativity (ERN); reward; social

The disposition to engage in *social* behavior is a core feature of extraversion, which is considered a fundamental personality dimension by most personality theories (Eysenck, 1967; Fiske, 1949; Goldberg, 1990; McCrae & Costa, 1997). Extraverts have a preference for seeking, engaging in, and enjoying social interactions, whereas introverts prefer to avoid social situations and tend to be reserved, withdrawn or shy in social settings (Ashton, Lee, & Paunonen, 2002; Costa & McCrae, 1980; Eysenck, 1990; John, 1990). This social facet of personality, referred to as extraversion, appears in lexically, behaviorally and biologically derived taxonomies of personality (see Wilt & Revelle, 2009, for a review), suggesting that it is one of the most representative and essential personality aspects. As such, extraversion

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has been shown, at least partially, to explain a wide variety of human behaviors, including effective functioning across many domains ranging from cognitive performance (Matthews, 1992) and psychological well-being (Costa & McCrae, 1980; Trull & Sher, 1994) to socioeconomic status (Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007).

Given its crucial function as a powerful explanatory factor for human behavior, the core feature of extraversion as a *social* dimension of personality has received relatively little exploration in the contemporary social neuroscience. That is, while an increasing number of studies are investigating the neurobiological correlates of extraversion, most have reported findings consistent with enhanced reward sensitivity in extraverts (e.g., positive correlations with neural activity in dopaminergically innervated, reward-sensitive regions, including the ventral striatum, amygdala and medial prefrontal cortices; Canli et al., 2001; Cohen et al., 2005; Depue & Collins, 1999; Johnson et al., 1999). However, the core question of whether extraverts' neural circuits are more sensitive to *social* rewards per se, befitting the very definition of extraversion, remains largely unaddressed. Namely, it may be that the extraverts' enhanced sensitivity to reward is modulated by the nature of reinforcement, such that their neural circuitry is more sensitive to social, rather than non-social (e.g., monetary or other material) rewards. In other words, given that social engagement and preference for other people's company is one of the fundamental features of extraversion (cf. Ashton, Lee, & Paunonen, 2002), social stimuli – such as images of human faces – can potentially be more rewarding for extraverts relative to introverts.

Recently, some initial evidence related to this claim began to emerge: Fishman, Ng and Bellugi (2011) have found that variation on the extraversion dimension is strongly associated with the extent to which social stimuli evoke enhanced allocation of attention. Specifically, they demonstrated that individuals with higher extraversion scores exhibited greater index of attention to social (human faces) than non-social stimuli, as measured by the P300 component of the event-related potentials (ERPs). Because the two categories of stimuli – faces and flowers – had comparable stimulus properties and equivalent frequency of occurrence, this finding indicated that human faces are especially noteworthy for extraverts, in comparison to other visual stimuli, suggesting that social stimuli possess increased motivational significance for individuals characterized by extraversion. At the same time, smaller P300 amplitudes in response to faces found in introverts in comparison to extraverts may indicate that human faces are not a particularly attention-grabbing category of visual information for introverts. Overall, these findings suggest that extraversion is associated with enhanced processing of social stimuli, as signified by greater P300 amplitudes, likely due to a heightened intrinsic psychological significance that such stimuli carry for extraverts.

The present study was designed to expand on this notion by investigating whether social stimuli possess greater *rewarding* value for extraverts than for introverts, employing an ERP index of reward processing, the error-related negativity (ERN). The ERN (sometimes also referred to as Ne, for error negativity) is a negative-going ERP deflection that appears over fronto-central scalp sites within ~100 ms following an error commission (Gehring et al., 1993), or within ~200 ms following a presentation of feedback indicating erroneous performance (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Miltner, Braun, & Coles, 1997). Studies utilizing source localization (Dehaene, Posner, & Tucker, 1994), electrophysiological recording in monkeys (Gemba, Sasaki, & Brooks, 1986) and humans (Wang, Ulbert, Schomer, Marinkovic, & Halgren, 2005), and fMRI studies in humans (Carter et al., 1998; Debener et al., 2005) have all consistently identified anterior cingulate cortex (ACC) as the most likely neural generator of the ERN. Functionally, the ERN is considered to be elicited by a dopamine-driven system for reinforcement-based learning, which continually evaluates ongoing events, including our actions and corresponding

feedback, and applies information obtained from rewards and punishments towards updating our behavior (Holroyd & Coles, 2002). According to this view, the ERN is produced by a predictive error signal conveyed by this dopaminergic reward system to the ACC – one of the major termini of mesencephalic dopamine projections – to guide future selection of actions.

Further, evidence suggests that the ERN is particularly sensitive to the affective evaluation of response outcomes. For instance, errors committed on highly rewarded trials elicit larger ERN amplitudes than errors committed on poorly rewarded trials (Hajcak, Moser, Yeung, & Simons, 2005). Also, greater ERNs are found when participants are rewarded for being accurate rather than fast – that is, when instructions to be accurate make errors more salient or more valuable (Gehring et al., 1993). Thus, given this evidence that the ERN is sensitive to subjective motivational factors, combined with the ERN's theorized function as indexing the reward system signal to the ACC, it follows that the ERN should be greater when errors – or feedback indicating erroneous performance – are more valuable or motivationally significant. More specifically, because of the presumed motivational salience that social stimuli (namely, human faces) have for extraverts (e.g., Fishman et al., 2011), it is likely that individuals high on extraversion would exhibit larger ERN amplitudes on error trials followed by social feedback (expressed through faces) than on those followed by non-social feedback.

Hence, the present study was designed to explore the modulation of the ERN component elicited by social feedback as a function of one's extraversion, using a novel variation of the flanker task (Eriksen & Eriksen, 1974). A simple-choice flanker task was adapted such that performance on every trial was followed by a feedback message, with the feedback delivery mode being either social (feedback delivered through facial expressions) or non-social (feedback expressed by written words). Of critical interest was the contrast in error-related EEG activity between these two conditions – social vs. non-social feedback – while ensuring that they were associated with comparable error rates. It was hypothesized that extraverts, who by definition enjoy and seek the company of others, would find social feedback more rewarding than introverts – and, thus, exhibit larger ERNs – but that both groups would be similarly sensitive to non-social reward signals, demonstrating comparable ERN amplitudes. The key factor on which this prediction is based is the assumption that extraverts and introverts have differential motivational values that they assign to social stimuli, which, at the level of ERPs, should elicit differential ERNs on error trials followed by social feedback. The main question addressed by this study is whether information with social content carries greater rewarding value for the extraverts' neural circuits, than for those of introverts.

Method

Participants

Twenty-eight healthy young adults (15 females) between the ages of 18 and 40 (mean age = 21.5, $SD = 4.58$) participated in the study in exchange for cash. Participants were recruited as part of an ongoing multicenter research program and screened to rule out history of central nervous system (CNS) disorder or injury, current or past psychiatric conditions, and current use of medications affecting CNS. The average number of years of formal education was 13.5 years ($SD = 1.4$); the sample's ethnic composition was quite diverse, with 43% reporting their ethnicity as Caucasian, 35% as Asian-American, 11% as Hispanic, 7% as African-American, and 4% as Native American. Individual differences in extraversion were assessed using the 48-item Extraversion scale of the NEO Personality Inventory Revised (NEO PI-R; Costa & McCrae, 1992), from which Extraversion *T*-scores were calculated based on gender-specific normative data (with higher scores indicating higher Extraversion).

The Extraversion scale was administered following the ERP task, to avoid any unintended priming that might occur with use of introspective questions about one's personality.

Experimental Task, Stimuli and Procedure

All study protocols were approved by an Institutional Review Board. Participants completed a modified version of the Eriksen Flanker task (EFT; Eriksen & Eriksen, 1974) in which a central arrowhead, pointing to either left or right, was presented on each trial, flanked by four additional arrowheads (two on each side). There were two congruent conditions in which the center arrowhead pointed to the same direction as the flankers (“> > > >”, “< < < <”) and two incongruent conditions (“> < < >”, “< > > <”). Arrowheads were presented in black font against a white background, and were positioned in the center of the screen. While, overall, 50% of trials were congruent, the stimuli were presented pseudo-randomly such that each trial type (left vs. right central arrowhead; congruent vs. incongruent flankers) and each trial type transition occurred equally often.

Participants' task was to indicate, via a button press on a response box, whether the center arrowhead pointed to the right (press “2”) or to the left (press “1”). An individualized stimulus presentation duration, adjusted in accordance with each participant's cumulative average response time, was utilized to increase the number of error trials (necessary to elicit a robust ERN), and to equate the participants' individual error-rates at approximately 20%. On each trial, the participant's response was followed by a screen providing feedback regarding the performance on the latest trial: in the non-social blocks, the feedback message was delivered via written words (“Right”, “Wrong”, or “Speed up” for trials with slow reaction times as defined below), whereas in the social blocks the feedback was delivered by means of an image of a congruent facial expression, namely happy, smiling faces for correct trials and angry or disgusted faces for incorrect and slow trials. Overall, participants completed two blocks of the social feedback and two blocks of the non-social feedback (i.e., four blocks total), with 50 trials per block, yielding a total of 200 trials. The blocks were separated by self-paced rest breaks and their order was counterbalanced between participants.

Images of facial expressions used to deliver feedback in the social blocks were drawn from a pool of forty high-resolution color photographs displaying three different expressions (10 angry, 10 disgusted and 20 happy expressions). The images were sourced from the NimStim Set of Facial Expressions, a standardized, validated dataset of photographs of professional actors from diverse ethnic backgrounds expressing various emotions (Tottenham et al., 2009). The specific images (NimStim numbers 01, 02, 03, 05, 06, 07, 09, 10, 11, 14, 20, 22, 24, 26, 27, 28, 29, 36, 38, 43) were chosen for their high Kappa scores and proportion correct (average subset values of 0.864 and 0.923, respectively), indicating that these emotional expressions are recognized with a high degree of accuracy. Images of happy facial expressions were used to deliver positive feedback on correct trials; images of either angry or disgusted faces* were used to convey negative feedback on either incorrect or slow trials (the feedback for slow trials were distinguished from that for the incorrect ones by the phrase “Speed up” added at the bottom of the negative face image).

Each trial began with a central fixation cross for 500 ms, followed by a blank screen for 100 ms. Next, the stimulus was presented in the center of the screen for an individually adjusted

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*Both angry and disgusted expressions were included in the negative feedback condition following a pilot testing, during which ten individuals recruited for a separate study rated these images as most effective in delivering negative feedback. This is consistent with previous research (e.g., Ashworth et al., 2011) combining angry and disgusted faces for a negative affect condition, when negative-vs.-positive valence distinction is sought. In support of this approach, angry and disgusted facial expressions are processed by largely overlapping brain regions (e.g., insula), according to a recent meta-analysis (Fusar-Poli et al., 2009).

duration (as reasoned above), varying between 50 and 80 ms, followed by a blank screen allowing participants to respond, ad lib, for approximately 1,000 ms following the stimulus onset. Participant's response, to which ERPs were time-locked, triggered immediate presentation of feedback, which remained on the screen for 1,000 ms. Finally, a jittered inter-trial interval of 500–800 ms preceded the start of the next trial. At the beginning of each block participants were informed which condition would follow next, namely whether the feedback would be delivered via words or with facial expressions. Two practice blocks composed of 20 trials each, during which both speed and accuracy were emphasized, were administered prior to experimental blocks. Participants were informed – and reminded at the beginning of each block – that they should respond as quickly as possible while trying to avoid errors. If their error rate exceeded 30% on the previous block, they were instructed to respond with more care at the beginning of the next block.

EEG data acquisition and analysis

EEG data were recorded using NetStation 4.0, an EEG recording system with a 64-channel Geodesic Sensor Net with Ag/AgCl electrodes (Electrical Geodesics, Inc.; EGI, Eugene, OR). Data were sampled at 250 Hz and filtered offline with a 0.1 to 40 Hz bandpass filter. The filtered data were segmented into epochs starting 100 ms before response onset to 900 ms after response onset, subjected to automated artifact detection ($>70 \mu\text{V}$ in any one of the channels), corrected for vertical and horizontal eye movements (Gratton, Coles, & Donchin, 1983), re-referenced to average reference, and baseline-corrected using the average of the 100-ms pre-response epoch. Artifact-free trials were then averaged by experimental condition generating four separate average waveforms: correct vs. incorrect trials, separately for social and non-social feedback conditions.

Given the frontal-central scalp distribution characteristic of the ERN (cf. Hajcak, 2012), the ERN was defined as the most negative peak measured at frontal-central electrodes F1, F2, FC1, FC2, Fz, FCz, occurring in the time window from 50 to 200 ms post-response. This time window was chosen by visual inspection of the grand averaged waveforms.

Four participants were excluded from electrophysiological analyses because they had made too few errors (< 6) to produce stable, reliable ERP averages, on one or both feedback conditions; thus, all analyses involving ERP measurements were performed on 24 participants. The average number of artifact-free error trials per ERP average was 18.18 ($SD = 5.11$) in the non-social feedback condition and 14.89 ($SD = 3.30$) in the social feedback condition, with no average based on less than 10 trials.

Results

The participants' Extraversion T -scores ranged from 35 to 73, representing a wide spectrum of Extraversion: The NEO-PI-R manual interprets T scores of 56 to 65 as high and scores of 35 to 44 as low; while $T > 65$ and $T < 35$ are interpreted as very high and very low, respectively. The mean T -score for the sample was 56.6 ($SD = 10.9$). Extraversion scores were not significantly correlated with either age, or years of formal education (both r s $< .08$, p s $> .67$).

The sample was divided into Low, Mid-range and High Extraversion groups, based on the tertiary split, with cut-off points of 33% and 66% of the sample Extraversion T -scores distribution, resulting in semi-equal groups of $n = 9, 9$ and 10 , respectively.* To determine whether behavioral performance indices (reaction time (RT) and accuracy rates) were affected by the level of Extraversion, two separate (one for RT, and one for accuracy) 3 (Group: Low, Mid- and High Extraversion) by 2 (Feedback: social vs. non-social) repeated-measures ANOVA were performed. While there was no difference between the three groups

with regard to either RT (group effect $p = .16$) or accuracy ($p = .10$), there was a significant main effect of the feedback condition, such that, across all levels of extraversion, participants demonstrated higher RTs (slower responses; $F(2,25) = 39.73$, $p < .0001$) and lower error rates (greater accuracy; $F(2,25) = 29.47$, $p < .0001$) in the social-feedback (mean RT = 308.7 ± 35.1 ; mean accuracy = 84%) than in the non-social feedback condition (mean RT = 290.1 ± 31.1 ; mean accuracy = 78%). There were no significant interaction effects between extraversion and feedback condition, for either RT or accuracy (both p s $> .27$).

Figure 1 represents the ERP waveforms at FCz (a midline frontal electrode, where the ERN is typically at its maximum), averaged across individuals with Low, Mid- and High Extraversion, separately for correct and error trials in the social and non-social feedback conditions. As anticipated, the ERN, a characteristic large negative deflection associated with error trials, was observed starting shortly after response execution, at 50 ms to 100 ms post-response, and peaking at approximately 150–170 ms. Visible in this plot is an apparent difference in ERN amplitude between the social and non-social feedback conditions within Mid- and High Extraversion groups, whereas the difference between the two feedback conditions is not readily evident in the Low Extraversion group. To quantify these patterns, the ERN amplitude was derived as the maximum negative voltage among the six frontal-central electrodes in the 50–200 ms window, as detailed in Methods. First, a 2 (Trial: correct vs. error) by 2 (Feedback: social vs. non-social) within-subjects repeated measures ANOVA confirmed that the ERN amplitude was significantly greater (i.e., more negative in voltage) on error trials than on correct response trials, in both social ($F(1,23) = 7.20$, $p = .01$) and non-social feedback conditions ($F(1,23) = 14.23$, $p = .001$), indicating that the present experimental task – despite the novel feedback manipulation – elicited a typical ERN component, consistently with previous reports using analogous flanker stimuli.

Next, to test the hypothesis that ERN amplitude varied systematically as a function of extraversion and feedback condition, a 2 (Feedback: social vs. non-social) by 3 (Group: Low, Mid- and High Extraversion) repeated-measures ANOVA was conducted. While there was no significant group effect ($F(2,21) = 1.78$, $p = .20$; $\eta^2_p = .09$), there was a significant main effect of feedback ($F(1,21) = 5.85$, $p = .02$; $\eta^2_p = .22$), such that, overall, the ERN was greater in the non-social ($M = -10.4 \pm 1.55 \mu V$) than the social feedback condition ($M = -6.3 \pm 1.07 \mu V$). However, this was qualified by a significant interaction between extraversion and feedback mode ($F(2,21) = 3.68$, $p = .04$; $\eta^2_p = .26$), indicating that social vs. non-social feedback elicited differential ERN patterns across the three levels of extraversion. To further explore this significant interaction effect, two separate follow-up one-way ANOVAs, with extraversion groups as a between-subjects factor, were performed for the social and non-social feedback conditions. These analyses revealed that while there was no significant difference between the groups with respect to the ERN in the non-social feedback condition ($p = .73$), there was a significant group difference in the social feedback condition, such that, contrary to the prediction, the Low Extraversion group had significantly greater (i.e., more negative in voltage) ERNs than either Mid- ($p = .02$) or High Extraversion groups ($p = .005$). These differences are depicted in Figure 2, which plots mean error-elicited ERN amplitude for social and non-social feedback conditions, across the three levels of extraversion. Finally, a within-subjects comparison between the social and non-social feedback conditions tested separately for each extraversion group with three paired-samples t -tests revealed that High Extraversion group had significantly greater ERNs in the non-

* As expected based on the NEO-PI-R manual and norms, the Low Extraversion group included significantly more females than the Mid- and High Extraversion groups, $F(2, 27) = 5.22$, $p = .01$; pairwise comparison p values = .01. Both Mid- and High Extraversion groups were characterized by equal number of males and females (pairwise comparison $p = .46$). The mean Extraversion T -scores for Low, Mid- and High Extraversion group were 43.5 ± 6.2 ; 58.5 ± 2.4 and 66.7 ± 4.3 , respectively.

social than social context ($p = .02$). There was no significant difference between feedback conditions in either Low- ($p = .51$) or Mid-Extraversion group ($p = .16$).

To confirm this pattern while considering Extraversion more appropriately as a continuous variable, a follow-up correlation analysis was performed. Pearson's correlations revealed that the ERN amplitude elicited by error trials in the social feedback condition was significantly correlated with Extraversion scores ($r = .60$, $p = .002$), such that as Extraversion scores increased, ERN amplitude became less negative, thus resulting in the positive correlation (see Figure 3). Given the relatively small sample size, a bootstrapped correlation analysis using 10,000 samples was performed; it computed a 95% confidence interval ranging from .22 to .84 ($SE = 0.16$), indicating that this effect was not driven by outlying values. On the other hand, there was no significant (nor sizeable) correlation between individuals' Extraversion scores and ERN amplitude during the non-social (i.e., verbal) feedback blocks ($r = .06$, $p = .77$; see Figure 3), indicating that the association between Extraversion and ERN was specific to the *social* feedback.

Discussion

Following up on the recent evidence that social stimuli evoke preferential processing and enhanced attention – as indexed by the ERPs – in extraverts as compared to introverts (Fishman et al., 2011), the present study set out to explore whether social stimuli also possess greater *rewarding* value for extraverts' neural circuits than for those of introverts. Employing the ERN, an ERP index of reward processing shown to be sensitive to motivational factors, the study's chief prediction was that extraverts would exhibit greater ERN amplitudes under the conditions where feedback regarding their performance is delivered via social channels (by way of facial expressions) because of a greater sensitivity to social than to non-social reward signals.

The study's main finding was that feedback delivery mode was indeed predictive of the extent to which the ERN amplitude varied as a function of individual differences in extraversion. Namely, a significant interaction effect between extraversion and feedback revealed that while *all* participants produced similar error-elicited ERNs under non-social feedback condition, ERNs elicited in the context of social feedback varied across different levels of extraversion. However, the directionality of this latter ERN modulation observed in the social feedback condition was contrary to the one hypothesized, in that extraverts demonstrated smaller – rather than greater – ERNs, as compared to introverts. Moreover, the degree to which the ERN was attenuated in the social feedback condition was strongly predicted by the individual's score on Extraversion: the higher the score, the more reduced the ERN, with the correlation coefficient indicative of a large effect size.

Given the evidence of enhanced ERN found (a) in individuals with performance anxiety (i.e., those who worry about making errors; Hajcak, McDonald, & Simons, 2003), generalized anxiety (Weinberg, Olvet, & Hajcak, 2010) and obsessive compulsive traits or disorder (Gehring, Himle, & Nisenson, 2000; Hajcak, Franklin, Foa, & Simons, 2008; Hajcak & Simons, 2002), and (b) following manipulations that make errors more salient, either through incentives (Hajcak et al., 2005; Pailing & Segalowitz, 2004) or task instructions that emphasize accuracy over speed (Falkenstein et al., 2000; Gehring et al. 1993), the notion of the ERN sensitivity to the perceived consequences of making an error, or to the error subjective value, has been put forward (Hajcak, 2012). In this context, the present finding of *diminished* ERN amplitudes in extraverts in the social feedback blocks suggests that, under social conditions, extraverts either find errors to be less salient, or are less concerned about the consequences of having made an error. In other words, the observation that ERNs produced by extraverts during social feedback condition were smaller

than their ERNs when feedback was of non-social nature is indicative of a diminished concern over errors, or decreased engagement in response monitoring under social conditions. This interpretation is consistent with a recent conceptualization of the ERN as a neural index of defensive reactivity in service of protecting the organism (Weinberg, Riesel, & Hajcak, 2012): to the degree that errors, as motivationally-salient events, require attention and corrective action, the ERN signals to the brain whether it needs to alter behavior to achieve a desired goal. From this point of view, the extraverts' attenuated ERNs in the social feedback blocks suggest that, perhaps, social context primes extraverts – but not introverts – to be less sensitive to the unfavorable outcomes, resulting in diminished error signaling by the ERN. In other words, it is possible that for individuals characterized by high sociability (i.e., extraverts), the punitive value of the negative feedback associated with errors is modulated (i.e., lessened) by the perceived rewards of engaging in a task that affords exposure to human faces, regardless of their valence. The extraverts' tendency to engage in social interactions might make social contexts more predictable and therefore more pleasant, resulting in lessened negative reactivity to seemingly unpleasant events such as errors. Parenthetically, this interpretation is consistent with a recent finding by Nash and colleagues that approach motivation is associated with diminished ERN, suggesting that reduced sensitivity to negative outcomes presumably reflected in the approach motivation “may mute reactivity to aversive events” (Nash et al., 2012, p. 98). Conversely, the presence of the social agent delivering feedback in the social condition may be less appealing and potentially more aversive to introverts, resulting in larger ERNs, consistent with prior findings demonstrating a direct relationship between negative valence and enhanced ERN amplitudes (e.g., Hajcak et al., 2004).

Importantly, because the ERNs produced by the extraverts when feedback was delivered via facial expressions differed from those produced by the introverts during *either* feedback condition, the above difference in the ERN amplitude cannot be attributed to personality-related differences in attentiveness to task resulting in differential task performance (the ERN amplitude is known to increase as error rates go up). In fact, analyses of behavioral performance indices, namely RT and error rates, revealed no main effect of group, nor a significant interaction between extraversion and feedback condition. Therefore, behavioral data rule out the interpretation that the observed ERN effects reflect personality-driven differences in performance. Rather, the ERN effects appear to be produced by the contrast between the two types of feedback delivery, the chief difference between which lied, by design, in the assumed greater salience of human faces for extraverts. The results, indeed, reflected this differential *motivational* value; however, the interpretation – and the finding itself – was in contrast with the original hypothesis that errors in social context might carry more punitive value for extraverts, thereby eliciting enhanced ERN amplitudes. Instead, the social context provided by the condition in which feedback was delivered via facial expressions appeared to depress the extraverts' affective responsivity to unfavorable outcomes, as reflected in the attenuated ERNs.

Notably, these data assessed at a single point in young adulthood cannot shed light on whether these findings reflect current social attitude differences, or are a consequence of differential developmental trajectories of introverts and extraverts, the latter being characterized by life-long preferential attention to social stimuli (Fishman et al., 2011) and a resultant perceptual expertise with such stimuli. The present data also do not allow a determination of whether these effects are stable across development. Nevertheless, the results offer further support for the notion of differential neurobiological processes associated with two distinct personality profiles characterized by social approach and social withdrawal. Although a causal relationship cannot be inferred from these data (i.e., it is unclear whether one's extraversion/introversion might lead to specific alterations in neural circuitry via different lifetime experiences, or whether differential brain circuitry determines

one's extraversion), the findings suggest that individual differences in personality are related to meaningful individual differences in neural responses to social stimuli.

The results from this investigation provide further evidence that affective and motivational processes are reflected in the ERN brain signal and also offer additional support for theories of anterior cingulate function that posit motivational and evaluative capacities to this brain region (e.g., Devinsky, Morrell, & Vogt, 1995). Insofar as the ERN is an index of the dopaminergic reward system signaling to the ACC (cf. Holroyd & Coles, 2002), the present findings that, in extraverts the rewards of engaging in a social-context task outweighed the transient negative affect associated with errors, can be either due to a lesser response to the error warning signals (i.e., reduced activation of the amygdala, leading, in turn, to the lessened activation of the ACC/ERN signaling), and/or due to an increased activation of the reward system afforded, consequentially, by diminished signaling from the ACC to the nucleus accumbens (cf. Ernst, Pine, & Hardin, 2006). This would result in a heightened pleasure and a reduced ERN response (Segalowitz & Dywan, 2009), which was apparent in extraverts in the social feedback condition.

Finally, these data underline the importance of adjusting standard cognitive paradigms to more specifically test the questions of interest, especially when exploring individual differences. In particular, they illustrate that to predict an individual's response to errors, it is necessary to account for underlying personality dispositions that may influence sensitivity to motivational incentives.

In sum, the ERNs were similar across participants with different levels of extraversion when feedback was delivered verbally, in written mode, which was conceptualized as a non-social feedback delivery. However, the ERN was markedly reduced in extraverts when the feedback was delivered via social – facial expressions – means, an effect shown to be related to the degree of extraversion. This effect is interpreted to reflect the notion that engagement in response monitoring might be selectively affected by the incentives or consequences associated with a particular context in which performance takes place. Specifically, in extraverts the social feedback condition might have created a more positive context in which errors were evaluated as less unfavorable. While this interpretation almost certainly underestimates the complexity of the neural and psychological systems involved, it, nevertheless, provides a framework for future research and further predictions (e.g., whether extraverts, indeed, show diminished psychophysiological arousal, reduced amygdala activation, or more positive affect in the social feedback condition). More generally, these data highlight that social incentives do not have an equally strong reinforcing value for all people, and that social attitudes, as reflected in the individual differences on the personality trait of extraversion, seem to determine to what extent an individual “responds” to social rewards.

Acknowledgments

This work was supported by the National Institute of Mental Health (NIMH) fellowship awarded to the first author [5 T32 MH20002].

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*Highlights

We examined whether extraverts are particularly sensitive to social rewards.

An ERP component known to be sensitive to reward (ERN) was utilized.

The ERN was measured in either social or non-social condition.

Extraverts exhibited smaller ERNs than introverts during social blocks.

Extraverts find social contexts more predictable and less anxiety provoking.

Figure 1.

Response-locked ERP waveforms at FCz (midline frontal electrode, where ERN is at its maximum) for individuals with Low, Mid-range and High Extraversion scores, based on the tertiary split of the sample. Black vertical arrows (corresponding to zero time) mark response onset. Negative voltages are plotted as upward deflections.

Figure 2.

Mean error-elicited ERN amplitude (μV) measured as the most negative peak in the frontal-central electrodes, for social and non-social feedback conditions, as a function of extraversion level. Error bars represent ± 1 SE.

Figure 3. Scatter plots illustrating relationship between Extraversion scores and ERN amplitude, separately for social and non-social feedback conditions.