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# The error-related negativity as a state and trait measure: Motivation, personality, and ERPs in response to errors

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## Abstract

This study examines changes in the error-related negativity (ERN/Ne) related to motivational incentives and personality traits. ERPs were gathered while adults completed a four-choice letter task during four motivational conditions. Monetary incentives for finger and hand accuracy were altered across motivation conditions to either be equal or favor one type of accuracy over the other in a 3:1 ratio. Larger ERN/Ne amplitudes were predicted with increased incentives, with personality moderating this effect. Results were as expected: Individuals higher on conscientiousness displayed smaller motivation-related changes in the ERN/Ne. Similarly, those low on neuroticism had smaller effects, with the effect of Conscientiousness absent after accounting for Neuroticism. These results emphasize an emotional/evaluative function for the ERN/Ne, and suggest that the ability to selectively invest in error monitoring is moderated by underlying personality.

**Descriptors:** ERPs, Error-related negativity, Error negativity, Motivation, Conscientiousness, Neuroticism

Interest in behavioral monitoring and evaluative processes has been heightened by the discovery of an event-related potential (ERP) component referred to as the error-related negativity (ERN; Gehring, Coles, Meyer, & Donchin, 1990) or error negativity (Ne; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990). The ERN/Ne is observed best in response-locked averages (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991), and is typically observed following errors, peaking approximately 40–100 ms after key press error commission, and is maximal at frontocentral sites (Dehaene, Posner, & Tucker, 1994; Falkenstein et al., 1991). The ERN/Ne was originally theorized to represent the activity of a generic monitoring system that detects errors by signaling a mismatch whenever comparisons between the response and the outcome of response selection yield different results (Falkenstein et al., 1991; Gehring, Goss, Coles, Meyer & Donchin, 1993). Alternative accounts suggest the ERN/Ne reflects detection of response conflict (Carter et al., 1998) or perhaps the response comparison process itself (Vidal, Hasbroucq, Grapperon, & Bonnet, 2000).

However, studies have shown that the amplitude of the ERN/Ne component increases when monetary incentives are offered for accuracy (Gehring et al., 1993; Gehring & Willoughby, 2002a). This finding suggests that the ERN/Ne reflects more than just a cognitive process (i.e., detection of an event). Rather the ERN/Ne brain signal may index the emotional or affective response to the event taking place, be it error detection, detection of response conflict, or some other cognitive process. Perhaps it is not surprising then that source localization methods suggest that the anterior cingulate (AC) is the neural source for the ERN/Ne (e.g., Dehaene et al., 1994; Miltner, Braun, & Coles, 1997). Evidence from neuronal imaging and lesion studies indicate that there are two distinct subdivisions of the AC, a cognitive division located dorsally (Bush et al., 1998; Carter et al., 1998; Gemba, Sasaki, & Brooks, 1986), and a rostral-ventral affective division that is involved in the evaluation of emotional or motivational information (Shidara & Richmond, 2002; Whalen et al., 1998).

Use of the ERN/Ne measure particularly as a means of indexing affective processing is very exciting and perhaps clinically meaningful, as the ability to modulate behavior in line with one's motives and the salience associated with different outcomes is fundamental to goal-directed behavior. Nonetheless, there are still only a few studies that have examined the effect of motivation for the ERN/Ne. Thus, the present study attempted to replicate previous results showing increases in ERN/Ne amplitude when incentives for accuracy are present. It was also designed to extend and broaden current understanding by addressing some of the remaining questions regarding the way that affective processes influence the ERN/Ne, using both a motivational and a personality approach. These issues are discussed next.

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### **Motivational Findings**

Evidence of motivational effects for the ERN/Ne was first provided by Gehring et al. (1993) by changing performance incentives. In one condition, accuracy was emphasized by associating errors with financial penalties, in another condition speed was emphasized by offering bonuses for quick responses, and in a neutral condition, values were altered to produce an intermediate speed–accuracy level. They found that individuals produced larger ERNs when task instructions emphasized accuracy relative to the neutral condition, and very diminished ERNs when instructions emphasized speed. These findings are consistent with the view that motivation and affective processes are reflected in the ERN/Ne. However, in directing attention to speed rather than accuracy, they may have altered the salience associated with errors of speed (i.e., slow responses), even though the ERN/Ne was still examined in relation to choice errors. This makes it difficult to judge how the three conditions compare in terms of salience for errors of choice, and therefore it is still unclear from these results if gradual changes in error salience (or differences in incentive level) are reflected in the ERN/Ne.

In addition, a more recent investigation by Willoughby and Gehring (2002) found no differences in the ERN/Ne for errors associated with low or high penalties, suggesting that the size of a penalty has no impact on the ERN/Ne. Furthermore, results by Gehring & Willoughby (2002a) suggest that the motivational impact (i.e., gain–loss status) is more important than relative differences in monetary outcomes. Using a clever manipulation that compared the nature (gain or loss) and size of the outcome (5¢ and 25¢) in a monetary gambling task, they found that whereas the loss–gain status influenced the medial frontal negativity, the error–correct status or relative difference in monetary outcomes did not. However, there remains some debate as to whether the medial frontal negativity reported here is the same as the ERN/Ne component (e.g., Gehring & Willoughby, 2002b; Holroyd, Coles, & Nieuwenhuis, 2002). Thus, definitive answers regarding the impact of subtle changes in salience (small vs. large incentives) for the ERN/Ne awaits further study.

In the current investigation, the effect of changes in salience for the ERN/Ne was reexamined using several incentive levels. The payoff ratio for correct responses in each motivation condition was explicitly stated so that participants knew how they should perform to achieve monetary gains associated with accurate performance. Thus, effective motivational manipulations should be reflected in performance benefits. A further objective was to determine whether motivational manipulations increase attention and monitoring for all types of behaviors (in a generalized manner), or whether attention and monitoring are enhanced for only those aspects of performance that are specifically reinforced. This question is relevant to how we monitor and evaluate errors in our everyday lives, as there are often several different aspects of performance to attend to, some of which are more salient than others. Thus, it is important to understand what happens when more and less salient errors can take place at the same time within the same context.

### **Personality and Individual Differences**

Another means of looking at the ERN/Ne–salience relation is through studies of individual differences. If affective processes are reflected in the ERN/Ne, individual differences in this brain signal may reflect the extent to which an individual is emotionally invested in error monitoring. Indeed, the ERN/Ne amplitude has

been shown to vary with personality dispositions in which sensitivity to negative stimuli and monitoring problems are key elements. For example, Luu, Collins, and Tucker (2000) initially observed larger ERNs in individuals high in negative affect and emotionality (e.g., fear and anxiety). However, later in the course of testing, these same individuals showed diminished ERNs, perhaps, as the authors suggest, because they had disengaged from the task. Similarly, enhanced ERNs have been found in individuals with obsessive–compulsive disorder (OCD; Johannes et al., 2001), and Gehring, Himle, and Nisenson (2000) found the amplitude of the ERN/Ne to be positively related to OCD symptom severity. In addition, Dikman and Allen (2000) examined the ERN/Ne for reward and avoidance learning tasks in individuals scoring high and low (top and bottom 3%) on trait socialization (SO), a measure used to assess psychopathic tendencies. They found smaller ERNs in those scoring low on the SO measure, but only during tasks that penalize error responses. This interaction suggests that low trait SO individuals are not simply incapable of attending to their errors (the ERN for the low and high groups were the same in the reward condition), but rather are less sensitive to punishment. Thus, examining motivation by trait interactions may more clearly establish the role of error salience for observed differences. In the current investigation, the influence of five major personality dimensions was examined in relation to the ERN/Ne and different motivational states to determine whether performance motives are less stable for certain personality dispositions.

### **Current Study Objectives and Hypotheses**

In summary, the two main objectives of the present study were to determine (1) whether motivation manipulations have general and specific salience effects on the ERN/Ne, and (2) whether some personality types are less sensitive to the motivational states reflected in the ERN/Ne amplitude. To address these issues, participants completed a four-choice letter task in which there were two response dimensions, one based on a vowel/consonant distinction and a second based on an upper/lowercase distinction. One of the distinctions determined which finger they responded with and the second determined which hand they were to respond with, making it possible for participants to make more than one type of error (finger or hand) on any trial. General motivational effects for the ERN/Ne were examined by comparing conditions that offered no additional incentives for accuracy (no motivation) with a condition that offered small financial payoffs for both finger and hand accuracy (equal motivation). Furthermore, by offering greater financial payoffs for finger or hand accuracy (conditions 3 and 4; unequal motivation), specific effects of error salience could be examined. Participants also completed personality questionnaires assessing the five main personality dimensions (Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness) identified by Costa and McCrae (1992), as well as the socialization scale used by Dikman and Allen (2000).

Participants were expected to invest more attentional resources as the incentives for accuracy were increased. Following this general prediction, the ERN/Ne for finger and hand errors was expected to be larger in the equal motivation condition (EQM; where accuracy is rewarded and errors represent a loss of potential rewards) versus the no motivation condition (NM), consistent with the results reported by Gehring et al. (1993). Comparison of the ERN/Ne for hand and finger error types in the unequal motivation conditions allowed size effects of error

salience to be examined. A specific effect of error salience was predicted, that is, a crossover interaction was expected, with a larger ERN/Ne for error types associated with a greater loss of rewards. Personality factors were also expected to moderate the motivational effect observed for the ERN/Ne. Conscientiousness was of particular interest, as this dimension assesses cautiousness, discipline, and achievement-striving behavior (aspects of performance that are perhaps driven by more internal motives). Thus, it was predicted that individuals scoring high on Conscientiousness would be less sensitive to the motivational manipulations because they might be maximally engaged in the task regardless of the external incentives. Conversely, those high on Socialization and Neuroticism (which measures negative affect among other things) may be more sensitive to errors in general, and therefore may produce larger ERN/Ne.

## Method

### Participants

Eighteen undergraduate university students (13 women, 5 men) between the ages of 18 and 22 ( $M = 19.94$ ,  $SD = 1.26$ ) participated in this study. Two of the participants (1 woman, 1 man) were left-handed. Participants were recruited through the psychology subject pool and received a 3-hr research credit for their participation. Incentives for accurate performance in the four-choice letter task provided participants with an opportunity to earn up to \$15 based on their performance. Participants were screened to ensure that they were free of head injury causing loss of consciousness for a 20-min period or longer and/or central nervous system dysfunction. Informed written consent was obtained prior to testing in accordance with the Research Ethics Board at Brock University.

### Materials and Experimental Tasks

#### Questionnaire Material

*Health and history questionnaire.* A brief questionnaire was used to gather general background information as well as information concerning previous and ongoing health concerns. The first section of the questionnaire addressed educational history, including previous diagnosis of a learning disability, attention deficit disorder (ADD), depression, and so forth. The second part addressed previous and current incidence of health problems (including vision and hearing problems, movement problems, and serious infections or diseases) and the use of prescribed medications.

*Personality questionnaire.* This questionnaire consisted of 100 items from the International Personality Item Pool (IPIP; 2001; Goldberg, 1999). These items were selected to measure the same five domains (Neuroticism, Extraversion, Openness to Experience, Conscientiousness, and Agreeableness) as those assessed by the NEO Personality Inventory (NEO-PI-R) by Costa and McCrae (1992). Each item is rated on a 5-point scale. A 60-item version of the Conscientiousness scale was used, which includes six subscales (Self-efficacy, Orderliness, Dutifulness, Achievement-striving, Self-discipline, and Cautiousness), each composed of 10 items. The mean alpha reliability coefficient for the six subscales is .78 (ranging from .71 to .85;  $N = 501$ ), which is comparable to the reliability observed for corresponding subscales of the NEO-PI-R ( $M = .71$ ,  $N = 501$ ; Costa &

McCrae, 1992). Correlations between the Conscientiousness subscales of the IPIP-NEO and the NEO-PI-R are also fairly strong, ranging from .60 to .77 (or .87 to .99 when corrected for reliability; IPIP, 2001). The other four domains of the NEO were assessed using the 10-item scale version of the IPIP-NEO, as these domains were included primarily as a means of establishing discriminant validity. Coefficient alphas for each of the 10-item scales ranged from .77 to .86.

*Socialization scale.* Gough's Socialization (SO) scale from the California Psychological Inventory (CPI; Gough, 1957) was used to assess social attitudes and behaviors. This scale consists of 54 items requiring true or false responses to statements regarding socialization. One of the items was not included ("I think Lincoln was greater than Washington") because it appeared to be outdated and less relevant to a Canadian sample. Factor and item analysis have identified four main factors accounting for correlations among the items (Gough & Bradley, 1996). These include self-discipline and rule-observing behavior, self-confidence and positive emotionality, upbringing and family cohesiveness, and interpersonal awareness and reflective temperament. The SO scale is also believed to be conceptually related to the opposite pole of psychopathy, and perhaps to some extent, may be regarded as a measure of conscientiousness in a social context.

*Posttest questionnaire.* This questionnaire was administered orally, and provided information regarding the participant's subjective assessment of their performance during the different motivation conditions (e.g., which statement best describes performance: many more finger errors than hand errors, somewhat more finger errors than hand errors, equal number of finger and hand errors, somewhat more hand errors than finger errors, or many more hand errors than finger errors). Participants' behavioral performance and information regarding their estimated accuracy (e.g., 90% correct or better, 80–89% correct, 70–79% correct, 60–69%, or below 60%) and error awareness for each error type and motivation condition (e.g. very certain, certain, fairly certain, not certain at all) allowed assessment of the effectiveness of the motivational manipulations.

#### Experimental Paradigm: Four-Choice Letter Task

The effect of motivational states on error processing was assessed using a computer-administered four-choice letter task. Participants were presented with 1 of 16 letters, 1 at a time. On each trial, the letter was presented at the center of the computer screen for a duration of 250 ms. Stimulus onset asynchrony (SOA) was 1,100 ms. Four categories of letters were presented: uppercase vowels (A, E, U, and I), lowercase vowels (a, e, u, and i), uppercase consonants (D, G, H, R), and lowercase consonants (d, g, h, r). Each letter category was assigned a different key response involving either the left (L) or right (R) hand and the middle (M) or index (I) finger (i.e., four responses = LM, LI, RI, RM, corresponding to "a," "s," "k," and "l" key presses, respectively, on a standard QWERTY keyboard). Thus for each trial, the correct response was determined by two dimensions: one determined by the vowel/consonant distinction, and one determined by the uppercase/lowercase distinction. There was one correct response (correct hand and finger press) and three types of error responses based on this design (correct hand but wrong finger press, correct finger press but wrong hand response, and wrong finger plus wrong hand).

The paradigm consisted of 512 trials in total, with equal representation for each category (4 categories  $\times$  128 trials) and each letter form (16 letter forms  $\times$  32 trials). To maintain the difficulty level of the stimulus sequence throughout the task and across participants, a stimulus category was seldom presented more than twice in a row (i.e., there were very few back-to-back-to-back presentations of the same category). Response assignments were counterbalanced according to a  $2 \times 2$  design, to ensure that the hand (left and right) and finger (middle and index) assignments were counterbalanced across the two dimensions (vowel/consonant and uppercase/lowercase). For example, vowels were assigned a right hand response for 25% of the participants, a left hand response for 25% of the participants, a middle finger response for 25% of the participants, and an index finger response for the remaining 25%.

### Procedure

#### Screening Process

During initial telephone contact, potential participants were asked several questions to screen for suitability. The screening questions addressed the individual's age, and instances of head injury and/or neurological problems. To be considered eligible for study participation, individuals were required to meet the following criteria: (1) they were between the ages of 18 and 25, (2) they were free of nervous system dysfunction (e.g., epilepsy, multiple sclerosis), and (3) they had not sustained a head injury that resulted in loss of consciousness for 20 min or longer.

#### First Session

Participants completed the informed consent form, Health and History Questionnaire, and Socialization Scale in a small room in the Neuropsychology laboratory. After providing informed consent and questionnaire completion, participants were moved to the EEG and computer testing room to practice the four-choice letter task. Participants were run through a series of practice sets (each consisting of 32 trials) at increasingly faster presentation rates (SOA of 1,750 ms, 1,500 ms, and 1,100 ms). At each speed/difficulty level, participants were required to achieve a 70% minimum accuracy criteria before moving on to a faster presentation speed. The first session concluded when participants had achieved 70% accuracy (or better) at the presentation rate to be used during experimental test trials (SOA of 1,100 ms). This session took approximately 35 to 45 min to complete.

#### Second Session

The second session took place 1 to 4 days after the first session. After electrode application, participants were administered practice sets and experimental trials of the four-choice letter task. Participants completed the Posttest Questionnaire and Personality Questionnaire after finishing the letter task. Behavioral performance was reviewed and total earnings for each motivation condition were tallied by the researcher while participants completed the personality questionnaire. Participants were informed of their accuracy and paid their earnings after completing both questionnaires. The second session lasted approximately 3 to 3½ hr.

*Four-choice letter task—practice and experimental trials.* Task stimuli and assigned responses in the four-choice letter task remained constant across the first session and all experimental conditions of the second session. Practice sets were conducted in the same fashion as the first session (three presentation rates,

each set consisting of 32 trials). Thus, all participants demonstrated a 70% accuracy level at the 1,100-ms SOA presentation rate before beginning the experimental test trials.

The four-choice letter task was administered under four different motivation conditions. In three of the four conditions, participants' motivation to perform accurately was increased by informing them that they would have an opportunity to earn a small sum of money for correct responses. The total amount earned by participants during each motivation condition was based on the payoffs offered for each aspect of the task (correct hand responses, correct finger responses), and by overall accuracy rates for each aspect. In each motivation condition, the maximum earning was \$5 (i.e., 1 cent for each trial in which accurate finger and hand responses were made). However, in conditions 3 and 4, participants could maximize their earnings by performing the higher paid dimension more accurately than the lower paid dimension. These experimental conditions were administered in the following order:

1. No Motivation (NM): Participants were simply asked to perform the task quickly and accurately.
2. Equal Motivation (EQM): Monetary incentives were offered for accuracy, with equal incentives offered for accurate performance on both aspects of the task (0.5 cents for each correct vowel/consonant identification and 0.5 cents for each correct uppercase/lowercase identification).
3. Unequal Motivation (UM): Monetary incentives were offered for accuracy, but the payoffs for correct hand and correct finger responses were not equal. Instead, incentives favored one aspect of the task in a 3:1 ratio, such that the payoff for one type of correct response was three times greater (0.75 cents) than the other (0.25 cents). Thus, it was in the participant's best interest to attend more closely to one dimension of the task. Half the participants were offered greater payoffs for correct hand responses and the remainder were offered greater payoffs for correct finger responses.
4. Unequal Motivation (UM; reversed): Monetary incentives were again unequally distributed for correct hand and correct finger responses. The 3:1 payoff ratio provided during the third motivation condition was reversed so that the other aspect of performance was associated with greater payoffs.

Participants completed 2,080 trials of the four-choice letter task in total during the four experimental conditions with a constant SOA of 1,100 ms. The NM and EQM conditions each consisted of 512 trials with a 10-s break at the half point (after trial 256). The UM conditions each consisted of 528 trials with a 10-s break at the half point (after trial 264). Data gathered from the first 16 trials in the UM conditions were not included in the behavioral or ERP averages. These trials were added to give participants some time to adjust or change their mental set at the start of a new UM condition in accordance with the task instructions (e.g., greater incentives for finger or hand accuracy).

*Electrophysiological recording.* The electroencephalogram (EEG) was recorded from 44 scalp electrode sites with tin electrodes embedded in the nylon mesh material of a cap (Electro-Cap International, Inc). The electrode locations consisted of midline and lateral sites: Fp1, Fp2, Fpz, AF3, AF4, AF7, AF8, F1, F2, F3, F4, F7, F8, Fz, FC1, FC2, FC3, FC4, FC5, FC6, FCz, C1, C2, C3, C4, Cz, CP1, CP2, CP3, CP4, CP5, CP6, P3, P4, P7, P8, Pz, T7, T8, PO3, PO4, O1, O2, and Oz using AFz as the ground. However, only data from Fz, FCz, Cz, and

Pz were analyzed for the purpose of this study. EEG was recorded using the left earlobe as the reference and later referenced off-line using right ear data to derive an averaged-ear reference. A bipolar electrooculogram (EOG) was recorded from tin electrodes placed on the supraorbital ridge and outer canthus of the right eye. EEG and EOG impedances were maintained below 5 k $\Omega$  and 10 k $\Omega$ , respectively. EEG and EOG signals were amplified by a gain of 10,000, digitized with a 12-bit processor and a software gain of 1, time constant of 1 s, and a low-pass filter at 30 Hz. Signals were sampled at a rate of 256 points/s and were averaged time-locked to the response (the key press) starting 600 ms before the response and continuing 500 ms postresponse (epoch = 1,100 ms).

*Electrophysiological averaging and quantification.* ERPs were averaged according to response type (i.e., correct trials, finger errors, hand errors, and hand and finger errors) for each condition (NM, EQM, GFM, GHM). Trials with response times (RTs) less than 100 ms or greater than 1,000 ms were excluded from the averages. Correct-trial averaged ERPs excluded trials with deviations greater than  $\pm 75 \mu\text{V}$  on any of the 44 EEG channels or the bipolar EOG. For the majority of the participants, averaged correct-trial ERPs were based on 200 trials or more ( $M = 271$ ,  $SD = 115$ ). For the error trials, eye movement artifact was removed on a trial-by-trial basis by regression, with the option to entirely exclude those in which eye movement artifact did not appear to be corrected (Segalowitz, 1996).

A computer-assisted hand scoring peak-analysis program (Segalowitz, 1999) was used to quantify peak amplitude and latency of ERP error waveforms. The ERP waveforms were smoothed with a nonphase shifting 7-point filter (28 ms, approximately 3 db down at 16 Hz) prior to scoring to assist with identification of peaks. The ERN/Ne component was measured as the most negative peak occurring at FCz in the time window between 25 ms prior to and 175 ms after the incorrect response.

## Results

### Error Rate Data

All  $p$  values for analyses involving two or more within-subject factors were adjusted using the Greenhouse–Geisser correction for sphericity. Mean error rates (expressed as percentages) for each type of error (finger errors, hand errors, both finger and hand error, and no responses) and each motivation condition are provided in Table 1. Repeated-measures analysis of the total combined error rates revealed a main effect of motivation condition,  $F(3,48) = 2.73$ ,  $p = .05$ , with more errors made in the NM condition ( $M = 17.47\%$ ) compared to the EQM condition (12.65%), [planned comparison,  $t(17) = 4.61$ ,  $p < .001$ ]. Similar results were obtained when finger and hand errors were examined separately (see Figure 1, top panel). More finger and hand errors were made in the NM condition relative to the EQM condition, condition effect,  $F(1,17) = 19.87$ ,  $p < .001$ . Finger and hand error rates did not differ (error type effect,  $F < 1$ ).

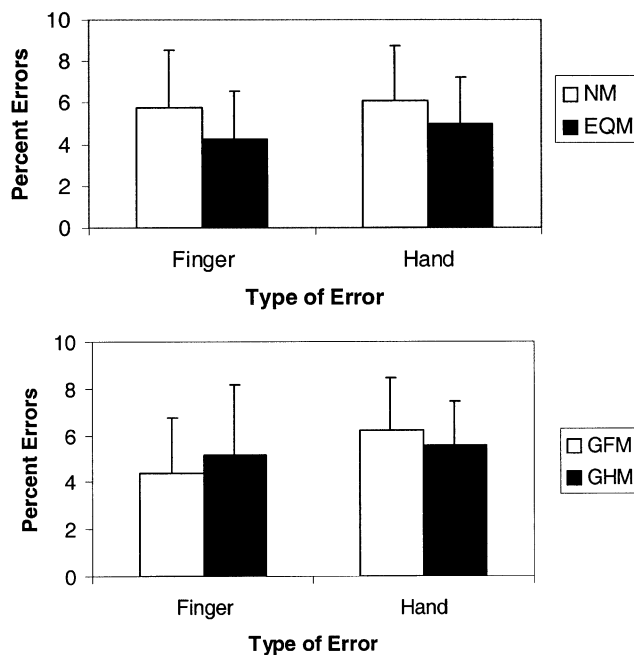
Examination of finger and hand error rates for the unequal motivation conditions suggest the incentive manipulations were effective. Two participants demonstrated extreme changes in performance in line with the incentives offered for accuracy [e.g., subject 9 made 4% finger errors versus 45% hand errors in the greater finger motivation condition (GFM), and 29% finger errors versus 9% hand errors in the greater hand motivation

**Table 1.** Mean Error Rates (Expressed as Percentage) for Each Motivation Condition

Error measure	Condition			
	NM	EQM	GFM	GHM
F error				
<i>M</i>	5.79	4.22	4.36	7.03
<i>SD</i>	(2.73)	(2.36)	(2.20)	(6.55)
H error				
<i>M</i>	6.11	4.95	8.87	5.64
<i>SD</i>	(2.64)	(2.25)	(9.60)	(1.96)
F and H error				
<i>M</i>	1.60	1.11	1.47	1.33
<i>SD</i>	(1.61)	(1.13)	(1.21)	(1.23)
No response				
<i>M</i>	3.97	2.38	2.53	2.15
<i>SD</i>	(3.72)	(1.75)	(2.52)	(2.44)
Total percent				
<i>M</i>	17.47	12.65	17.30	16.26
<i>SD</i>	(7.83)	(4.75)	(11.04)	(9.42)

Note:  $N = 18$ . F: finger, H: hand.

condition (GHM); subject 16 made 4% finger errors versus 15% hand errors in the GFM condition, and 14% finger errors versus 4% hand errors in the GHM condition]. Although these two participants clearly demonstrated the expected pattern, it was necessary to exclude them from the analysis because their data dramatically increased the sample variance. A  $2 \times 2$  repeated-measures analysis indicated that overall error rates did not differ across the unequal motivation conditions [GFM versus GHM,  $F(1,14) = 0.001$ ,  $p > .10$ ], or by type of error [finger error (FE)



**Figure 1.** Mean percent of finger and hand errors across motivational conditions. Error rates for the No Motivation (NM) and Equal Motivation (EQM) conditions are shown in the top panel ( $N = 18$ ). The lower panel provides error rates for the Unequal Motivation conditions [ $N = 15$ ; 2 participants were excluded (see text) and 1 participant did not complete the last condition]. Error bars represent the standard deviation.

versus hand error (HE),  $F(1,14) = 2.94, p > .10$ ]. However, the error rates changed according to motivation instruction and error type, as revealed by a significant interaction,  $F(1,14) = 5.34, p < .05$ . As illustrated in Figure 1 (lower panel), a crossover pattern is present with fewer errors tending to occur for each error type when greater incentives for accuracy were present.

**Subjective Ratings of Accuracy, Motivation, and Error Awareness**  
Although accuracy was slightly better in the EQM condition relative the NM condition (87% versus 82%, *n.s.*), mean perceived accuracy did not change, remaining in the 70–79% range across the four motivation conditions (Friedman's Test,  $\chi^2 = 1.43, df = 3, p > .10$ ). Furthermore, there was no relationship between subjective accuracy and performance for any of the motivation conditions (*rs* ranging from  $-.04$  to  $.41, ps > .05$ ), indicating that those who subjectively rated their accuracy higher were not performing significantly better.

Participants were also asked to comment on the overall effectiveness of the motivation manipulations. Less than half of the sample (39%) regarded the manipulations as effective in altering their performance. Those who regarded the manipulations as more effective were indeed more sensitive to the manipulations, as indicated by greater improvements in accuracy during high incentives ( $r = .54, p < .05$ ).<sup>1</sup> In addition, self-reports of error awareness were different across conditions (condition effect,  $F(3,51) = 4.99, p = .01$ ). Tukey's post hoc tests revealed that error awareness was reported to be higher in the NM condition relative to the GFM condition (mean difference = 0.58,  $t(17) = 3.29, p < .05$ ) and GHM condition (mean difference = 0.53,  $t(17) = 3.86, p < .05$ ).

### Response Time Data

Table 2 provides mean RT data for each response type and motivation condition.<sup>2</sup> The influence of response type for RT during the first two conditions was examined using a  $2 \times 4$  (NM, EQM  $\times$  correct, FE, HE, and both finger and hand error) repeated-measures design. As Figure 2 illustrates, the RT pattern was almost identical in the NM and EQM conditions,  $F < 1$ . However, there was an effect of response type,  $F(3,45) = 13.15, p = .002$ . Tukey's post hoc analysis indicated that RTs were faster when both the incorrect finger and incorrect hand were used relative to correct trials [mean difference = 176 ms,  $t(15) = 4.08, p < .05$ ], finger errors [mean difference = 158 ms,  $t(15) = 3.70, p < .05$ ], and hand errors [mean difference = 133 ms,  $t(15) = 3.23, p < .05$ ]. Similar results were observed when RTs in the unequal motivation conditions were examined (see Figure 2, lower panel;  $n = 13$ , as trials with both finger and hand errors were typically infrequent). A main effect of response type was found,  $F(3,36) = 5.15, p = .03$ , with trials with both errors (finger and hand) associated with faster RT relative to correct trials [mean difference = 97 ms,  $t(12) = 2.54, p < .05$ ] and finger error trials [mean difference = 82 ms,  $t(12) = 2.39, p < .05$ ].

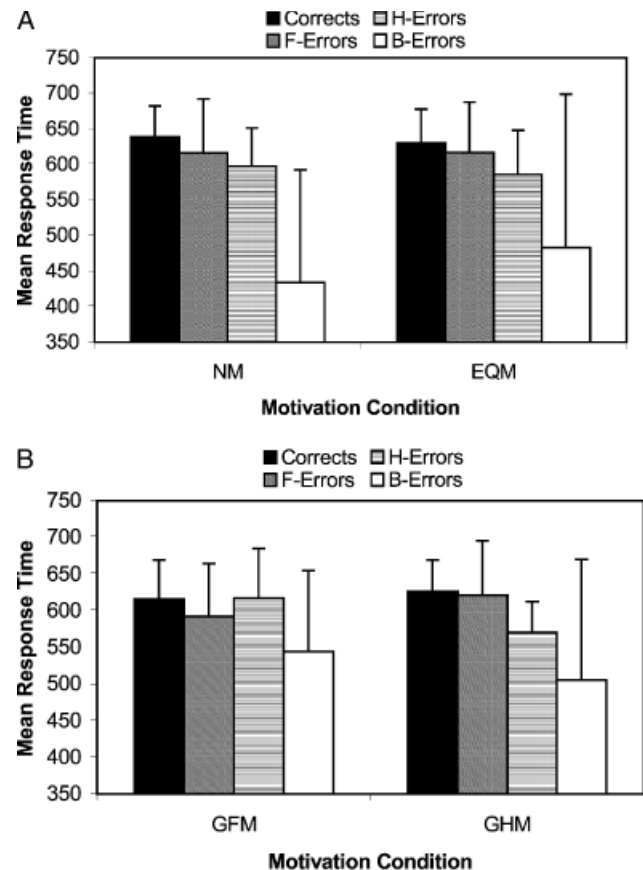
These findings suggest that participants were most likely to make erroneous finger and hand selections on the same trial when they had responded impulsively. However, correlations between error rates and correct RTs did not suggest a speed–

**Table 2.** Response Time Data for the Four Motivation Conditions

Response type	Condition			
	NM	EQM	GFM	GHM
Correct trials				
<i>M</i>	635	626	614	621
<i>SD</i>	(44)	(50)	(55)	(46)
<i>n</i>	18	18	18	17
F errors				
<i>M</i>	619	612	591	623
<i>SD</i>	(72)	(72)	(76)	(81)
<i>n</i>	18	18	18	17
H errors				
<i>M</i>	597	582	605	568
<i>SD</i>	(51)	(64)	(75)	(43)
<i>n</i>	18	18	18	17
F and H errors				
<i>M</i>	435	483	529	525
<i>SD</i>	(149)	(216)	(136)	(175)
<i>n</i>	18	16	17	14

Notes: Response times that were less than 100 ms or longer than 1,000 ms were excluded from the analysis. F: finger, H: hand.

accuracy trade-off. Instead, individuals demonstrating a lower error rate also tended to have faster correct RTs in the NM and EQM conditions,  $r(18) = .71, p < .01$  and  $r(18) = .47, p < .05$ , respectively. In addition, a one-way repeated-measures analysis



**Figure 2.** Mean response time for all responses types for the no motivation (NM) and equal motivation (EQM) conditions ( $N = 16$ ; top panel) and the greater finger motivation (GFM) and greater hand motivation (GHM) conditions ( $N = 14$ ; lower panel). F: finger, H: hand, B: both. Error bars represent the standard deviation.

<sup>1</sup>Incentive-related improvements in accuracy were measured by summing difference scores for FEs (GHM – GFM) and HEs (GFM – GHM).

<sup>2</sup>All RT data were submitted to a logarithmic base 10 transformation prior to statistical analysis.

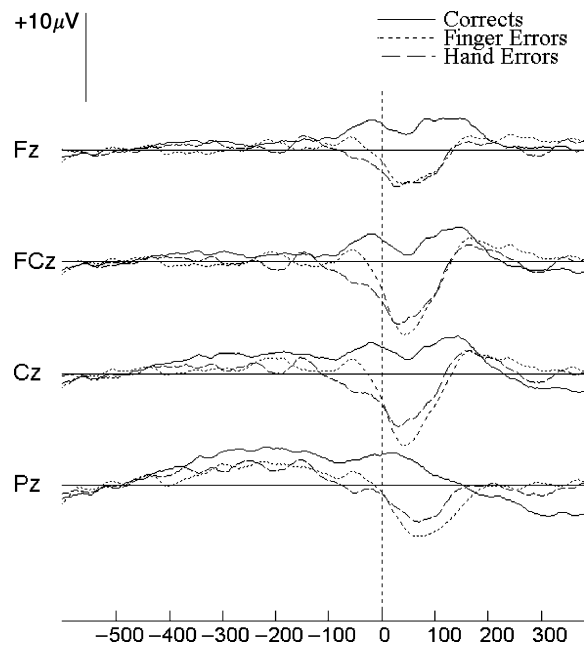
of correct RTs for the four conditions revealed significant RT differences across motivation conditions,  $F(3,48) = 3.27, p < .05$ . Tukey's post hoc analysis indicated that correct trial RT was slower in the NM condition ( $M = 636$  ms) relative to the GFM ( $M = 614$  ms),  $t(17) = 3.24, p < .05$ . These findings along with error rate data suggest that participants' performance improved over time from the initial testing condition (NM condition) both in terms of accuracy and RT. It is possible then that the enhanced performance in the EQM condition relative to the NM condition was due to practice effects rather than greater effort induced by incentives.

### ERN/Ne Findings

**Descriptives.** The ERN/Ne was measured in response-locked ERP averages, relative to an early baseline (600 ms to 400 ms prior to the response). Figure 3 provides the grand averaged ERP waveforms for finger and hand errors and correct trials in the NM condition ( $N = 18$ ).<sup>3</sup> The ERN/Ne was observed as a negative deflection (maximal at FCz) starting 50 ms to 100 ms prior to the response and peaking approximately 35 ms after the response for hand errors ( $-10 \mu\text{V}$  peak) and slightly later for finger errors (approximately 50 ms postresponse,  $-11 \mu\text{V}$  peak). A slight negative deflection was also observed in the ERP waveforms for correct trials, but it was more gradual and less extreme than that observed for errors trials.

**General motivational effects.** The main goal of this investigation was to determine the effect of manipulating error salience for the ERN/Ne. Participants were expected to invest more attentional resources as the incentives for accuracy increased, resulting in a larger ERN/Ne for finger and hand errors in the EQM condition relative to the NM condition. To test this hypothesis, a  $2 \times 2$  repeated-measures analysis of the ERN/Ne amplitude was performed for condition (NM, EQM) and error type (FE, HE). The motivation effect was not present. Instead, there appears to be a ceiling effect, with the addition of incentives in the EQM condition ( $M = 8.41 \mu\text{V}$ ) unable to produce a significant change in the ERN/Ne amplitude from the initial NM condition ( $M = 8.53 \mu\text{V}$ ),  $F < 1$ , perhaps because participants were highly motivated when beginning the testing experience. Furthermore, the ERN/Ne for FEs and HEs was similar (error type effect,  $F < 1$ ), and the Condition  $\times$  Error Type interaction was nonsignificant,  $F(1,17) = 4.24, p > .05$ .

**Salience-specific effects.** In each of the unequal motivation conditions, the overall level of incentive for accurate performance was similar, but the incentives for finger and hand accuracy were different, favoring one or the other in a 3:1 ratio. To determine if specific salience effects for the ERN/Ne were present, the ERN/Ne for finger and hand errors was examined for difference between errors associated with a small (low incentive) or large loss of rewards (high incentives). If salience has a specific effect on the ERN/Ne amplitude, then an interaction effect should be observed, with larger ERNs when greater incentives were offered for each error type. This hypothesis was tested by examining ERN/Ne amplitudes both within and across the unequal motivation conditions, using a  $2 \times 2$  repeated-measures analysis of condition (GFM, GHM) and error type effects (FE, HE).



**Figure 3.** Grand-averaged response-locked ERPs ( $N = 18$ ) for correct, finger error, and hand error trials in the NM condition. The vertical dashed line represents the response on the time scale. ERPs are presented relative to a 200-ms baseline of 600 to 400 ms prior to the response. F: finger, H: hand.

Although the interaction did not reach significance,  $F(1,16) = 1.33, p > .10$ , mean amplitudes were in the direction consistent with a specific salience effect: GFM-FE =  $-7.52 \mu\text{V}$ , GFM-HE =  $-6.06 \mu\text{V}$ , GHM-FE =  $-6.86 \mu\text{V}$ , and GHM-HE =  $-7.52 \mu\text{V}$ .

### Personality Factors

**Psychometric analysis of personality measures.** There was a considerable range in the Conscientiousness scores obtained from our sample ( $Min = 107, Max = 181, M = 140.22, SD = 22.27$ ) with a possible range of 0 to 240. Intercorrelations between Conscientiousness subscales and other personality measures are provided in Table 3. None of the other NEO-PI factors were strongly related to Conscientiousness, though Neuroticism and Openness to Experience approached significance,  $r = -.43, p = .08$  and  $r = -.46, p = .06$ , respectively. Gough's Socialization Scale was included because it was believed to index caring or emotional investment like the Conscientiousness scale, but more at a social level than the conscientiousness measure. Correlational findings provided some support for these assumed similarities, as a positive relationship was observed between Conscientiousness and Socialization scores ( $r = .52, p < .05$ ). In addition, Neuroticism scores were found to be inversely related to the Socialization measure,  $r = -.52, p < .05$ .

**The ERN/Ne across motivation and personality factors.** Although motivation effects were not observed for the entire sample, there was evidence that error salience was reflected in the ERN/Ne for some individuals. Conscientiousness was predicted to interact with motivation such that the ERN/Ne for those scoring high on the Conscientiousness scale would be less sensitive to the motivational manipulations. High and low Conscientiousness groups were formed using a median split

<sup>3</sup>ERPs averages for trials where both finger and hand errors were committed were not included because for many participants there were not enough trials ( $n < 6$ ) to produce a stable averaged waveform.

**Table 3.** Intercorrelations among Conscientiousness Subscales and Other Personality Scales

Conscientiousness subscales	2	3	4	5	6	7	8	9	10	11	12
1. Self-efficacy	.26	.17	.21	.29	.54*	.56*	-.42	.47	-.03	-.42	.41
2. Orderliness	–	.25	.33	.38	.45	.76***	0	.09	-.57*	-.16	.21
3. Dutifulness		–	.18	.32	.45	.54*	-.36	-.13	-.14	.54*	.28
4. Achievement-Striving			–	.71**	.02	.65**	-.42	.12	-.2	-.1	.26
5. Self-discipline				–	.14	.76***	-.59*	.25	-.33	.06	.42
6. Cautiousness					–	.60**	0	-.25	-.3	-.13	.59*
7. Conscientiousness (C)						–	-.43	.15	-.46	-.1	.52*
8. Neuroticism (N)							–	-.35	.13	-.14	-.51*
9. Extraversion (E)								–	.33	-.17	-.14
10. Openness (O)									–	.08	-.36
11. Agreeableness (A)										–	-.13
12. Socialization (SO)											–

Notes: For all correlations  $N = 18$ . \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

procedure. As Figure 4 illustrates, the pattern observed in ERN/Ne amplitudes for the low and high Conscientiousness groups was consistent with this prediction: Individuals scoring higher on the Conscientiousness showed little variation across the conditions, whereas a motivational effect appears to be present for the low Conscientiousness individuals (i.e., larger ERN/Ne when incentives for accuracy were high). However, the three-way interaction (Condition  $\times$  Error Type  $\times$  Group) did not reach significance,  $F(1,15) = 1.01, p > .10$ . To provide a more powerful test of this effect, Conscientiousness scores were correlated with a single measure reflecting the magnitude of the motivation effect for ERN/Ne amplitude. This measure was derived by summing differences scores reflecting the motivation effect for error negativities associated with FEs (GFM – GHM) and the motivation effect associated with HEs (GHM – GFM). In support of the third hypothesis, correlational analysis revealed a significant negative relationship between Conscientiousness scores and the motivation effect for the ERN/Ne,  $r = -.58, p = .01$  (see Figure 5), indicating that larger motivation effects were associated with smaller Conscientiousness scores.<sup>4</sup> Furthermore, the partial correlation between Conscientiousness and motivational effects for the ERN/Ne remained significant when differences in behavioral performance across the unequal conditions was accounted for,  $pr = -.57, p = .02$ . To test the discriminant validity of the Conscientiousness measure, the relationship between the motivation effects for the ERN/Ne and the other personality measures were examined. Correlations between the motivation effects for the ERN/Ne and Extraversion, Openness, Agreeableness, and Socialization scores were nonsignificant,  $r$ s ranging from .13 to  $-.39, ps > .10$ . However, Neuroticism scores also predicted the motivation effect for the ERN/Ne,  $r = .74, p = .001$ . As illustrated in Figure 6, the relationship for Neuroticism and motivational effects is opposite to that observed for Conscientiousness: Those scoring higher on Neuroticism tended to display large motivational effects for the ERNs (i.e., larger ERN/Ne when incentives for accuracy were relatively high). In addition, a significant three-way interaction

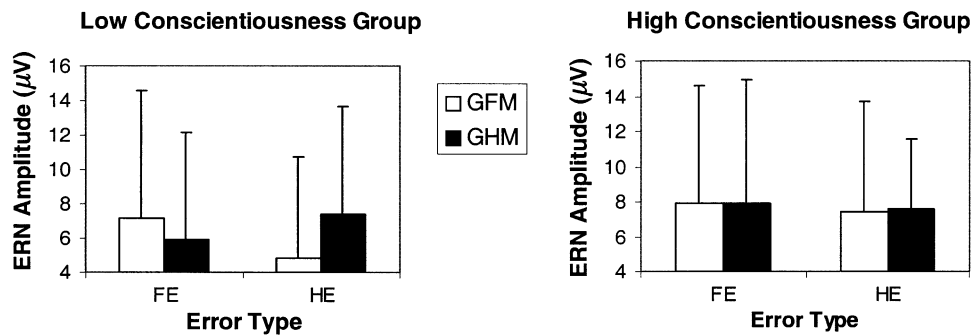
was observed when the sample was divided into high and low neuroticism groups based on a median split procedure,  $F(1,15) = 9.27, p = .008$  (see Figure 7). It is important to note however, that motivational effects for the ERN/Ne were not observed across the NM versus EQM conditions even when considering Neuroticism scores [three-way interaction,  $F(1,16) = 2.14, p > .10$ ], or Conscientiousness scores [three-way interaction,  $F(1,16) = 1.41, p > .10$ ].

Interactions observed with Conscientiousness and Neuroticism suggest that error salience is reflected in the ERN/Ne, but certain personality types are more likely to be sensitive to manipulations that alter salience or the significance of an error event. Further comparison revealed that there was considerable redundancy in the variance accounted for by the two measures: Conscientiousness accounted for 33.8% of the variance by itself, Neuroticism accounted for 55.3% of the variance by itself, but combined they only accounted for 60.6% of variance. Hierarchical regression analysis also indicated that Neuroticism accounted for significant variance (26.7%) above and beyond Conscientiousness (i.e., Neuroticism remained a significant predictor when Conscientiousness was entered first),  $F(1,14) = 9.49, p = .008$ . However, Conscientiousness could not predict the ERN/Ne motivation effect when Neuroticism was entered on the first step,  $F(1,14) = 1.88, p > .10$ . It is also interesting to note that those scoring higher on Neuroticism were more likely to perceive the motivation manipulations as effective,  $r = .69, p = .005$ , whereas the relation between Conscientiousness and these perceptions did not reach statistical significance,  $r = -.40, p < .10$ .

*Post hoc analysis of personality and ERN/Ne amplitude.* For the purpose of comparing our findings with those of Luu et al. (2000), we also examined the relationship between personality traits and the size of the ERN/Ne amplitude. Unlike Luu et al., none of the personality measures (including Neuroticism and Conscientiousness) were related to the size of the ERN/Ne amplitude observed in the initial testing condition (NM condition),  $ps < .10$ . However, similar to Luu et al., there was a trend of amplitude changes over time, but the amplitude changes were not different for high and low neurotics [nonsignificant Testing Order  $\times$  Neuroticism interaction,  $F(1,15) = 1.29, p > .10$ ]. Specifically, we found that ERN/Ne amplitude tended to decrease from the first half of testing (the NM and EQM conditions  $M = 8.43 \mu V$ ) to second half (the GFM and GHM conditions  $M = 6.99 \mu V$ ),  $F(1,16) = 3.84, p = .07$ . Thus, for the current investigation, personality predicted motivation-related

<sup>4</sup>A significant negative correlation was also observed between Conscientiousness and the motivation effect for the ERN when the motivation effect measure was based on residual scores rather than difference scores ( $r = -.45, p = .03$ , one-tailed). The FE ERN/Ne residual was formed by regressing the ERN for FE in GHM condition from that from the GFM condition and saving the residual. Similarly, the HE ERN/Ne residual was derived by regressing the ERN for HE in GFM from that from the GHM and saving the residuals. These residuals were added together to measure the overall motivation effect for the ERN.





**Figure 4.** ERN/Ne amplitude for low and high conscientiousness groups across condition and error type. Low ( $n = 9$ ) and high conscientiousness ( $n = 8$ ) groups were formed using a median split procedure. Note that although the three-way interaction did not reach significance,  $F(1, 5) = 1.01$ , n.s., the pattern of means was in the predicted direction: Low conscientious individuals showed more of a motivational effect than the high conscientious individuals.

changes in the ERN/Ne, not amplitude changes over time or differences in the initial size of the ERN/Ne.

**Discussion**

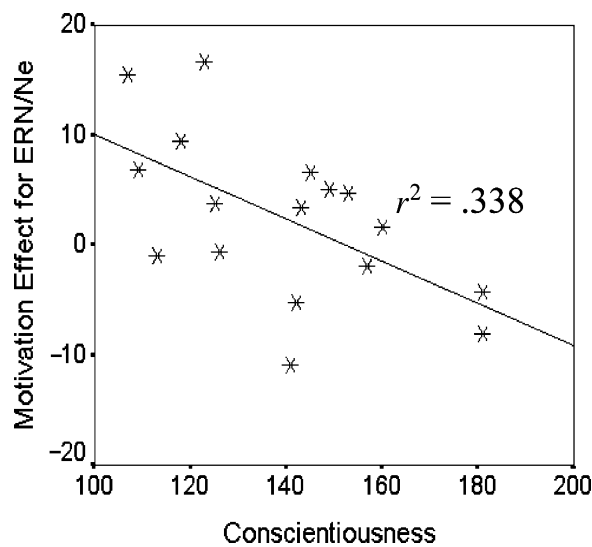
**Personality as a Moderating Variable for Motivation-Related Changes**

Evidence from the current investigation supports the contention that affective processes are reflected in the ERN/Ne brain signal, though changes in the ERN/Ne related to motivation were only observed for some personality types. Thus, findings from the present investigation like those of Dikman and Allen (2000) most clearly demonstrate the importance of personality as a moderating factor in predicting state or motivational changes. However, socialization did not prove to be an important personality measure in the present investigation. This may have been due to the considerable differences in sample distribution across the studies, with the investigation by Dikman and Allen using

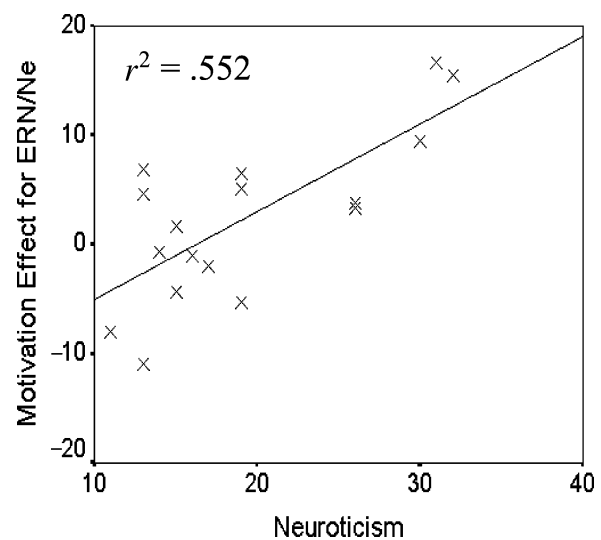
individuals with more extreme socialization scores (i.e., top and bottom 3% from a sample of 2,244 students). Nonetheless, two trait measures were identified that influenced the ERN/Ne-error salience effects. Interactions involving Conscientiousness and Neuroticism suggest that error salience is reflected in the ERN/Ne, but those scoring low on Conscientiousness or high on Neuroticism were more likely to be sensitive to manipulations that alter the salience or the significance of an error event. It is important to recognize that if personality measures had not been examined in this investigation, our conclusions regarding motivational effects for the ERN/Ne would have been very different because these effects were not observed across the entire sample. Thus, consideration of personality factors may have allowed us to recognize more subtle motivational differences.

**Conscientiousness versus Neuroticism**

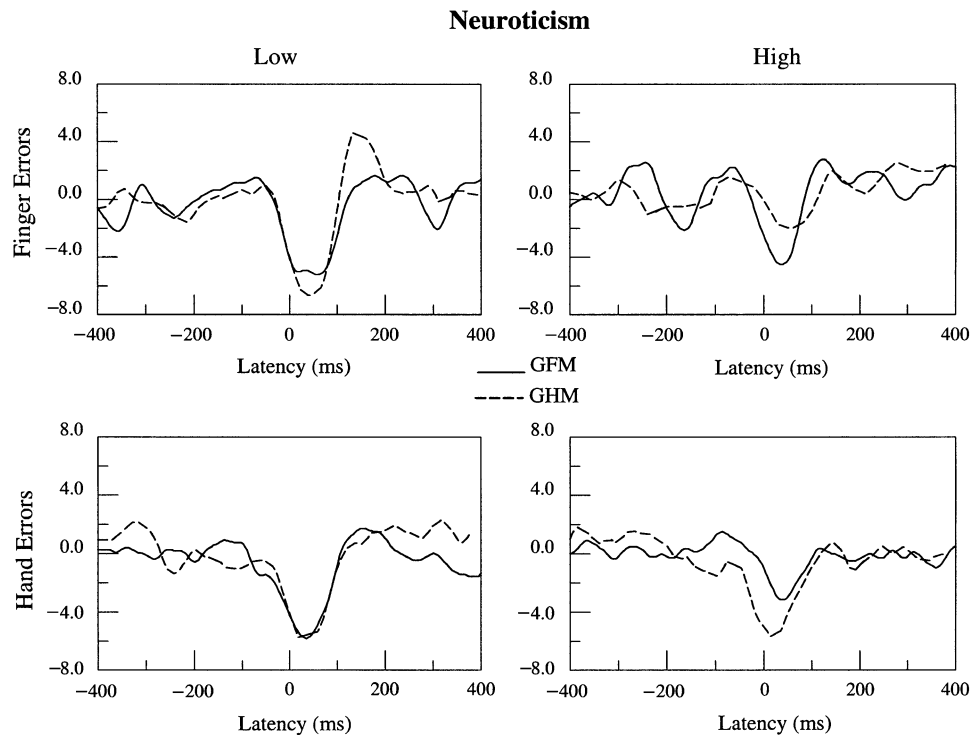
It was predicted that those scoring high on Conscientiousness would be less sensitive to the motivational manipulations because they would be motivated to perform well regardless of external incentives, and therefore, error salience would be more stable for them. The data did provide support for the hypothesis regarding



**Figure 5.** Scatterplot of the motivational effect for the ERN/Ne as a function of Conscientiousness scores. The ERN/Ne motivational effect scores were based on calculation determining the extent to which the ERN for FEs was larger in the GFM versus GHM conditions, and the extent to which the ERN for HEs was larger in the GHM versus GFM conditions. These separate calculations were then averaged together to provide an overall measure of ERN motivational effects.



**Figure 6.** Scatterplot of the motivational effect for the ERN/Ne as a function of Neuroticism scores. Note that the relationship between motivational effect for the ERN/Ne and Neuroticism is opposite to that found for Conscientiousness.



**Figure 7.** Grand-averaged response-locked ERPs for low and high neuroticism groups for the unequal motivation conditions. Low ( $n=9$ ) and high neuroticism ( $n=8$ ) groups were formed using a median split procedure. The three-way interaction (Condition  $\times$  Error Type  $\times$  Neuroticism) was significant,  $F(1,15)=9.27$ ,  $p=.008$ , with the high neurotic group tending to display more sensitivity to the motivational changes than the low neurotic group. GFM: greater finger motivation; GHM: greater hand motivation.

Conscientiousness, and the error salience effects for the ERN/Ne were not dependent on motivation-related changes in error rates. This was demonstrated in regression analyses in which partial correlations between Conscientiousness and motivational effects for the ERN/Ne remained significant when changes in behavioral performance was accounted for. However, Neuroticism accounted for more variance in ERN/Ne-motivational effects than did Conscientiousness. This suggests that Neuroticism is more directly related to the affective-related changes in the ERN/Ne.

Also remarkable was the fact that Neuroticism related to motivational ERN/Ne effects in a manner opposite to that observed for Conscientiousness: Motivation-related changes in the ERN/Ne were more likely to be observed in those scoring low on Conscientiousness or those scoring high on Neuroticism. This implies a negative relationship between Conscientiousness and Neuroticism scores in our sample, which was observed but only approached significance,  $p=.08$ . However, intercorrelations reported by Costa and McCrae (1992) in their validation study of the NEO-PI-R indicate that Neuroticism and Conscientiousness constructs are negatively related,  $r=-.53$ , and this was the strongest correlation existing among the personality scales. Furthermore, the negative correlation observed in the present study,  $r=-.43$ , is very similar to that reported in other studies using IPIP 20-item scales to measure Conscientiousness and Neuroticism (e.g.,  $r=-.40$ ; Saucier & Goldberg, 2002). Thus, the physiological evidence provided by the ERN/Ne brain signal lends external validity to these personality constructs, as motivation-related changes in the ERN/Ne related to Conscientiousness and Neuroticism in a manner consistent with factor analytic results for these personality domains.

The basis for the relationship or common link between the two constructs may be locus of control. For example, Shafer (1999) examined correlations among the five personality dimensions identified by Costa and McCrae (1992) and several other personality inventories, including Howarth's Additional Personality Factors (AFQ), which included a measure of external control. He found a positive relation between external control and Neuroticism,  $r=.19$ , and a negative correlation with Conscientiousness,  $r=-.42$ , indicating that high Neuroticism was associated more external control beliefs while high Conscientiousness was associated with fewer external control perceptions. In addition, Rossier, Rigozzi, and Berthoud (2002) documented a negative correlation between a measure of internal control and Neuroticism,  $r=-.35$ , and a positive correlation between internal control and Conscientiousness,  $r=.33$ . Similarly, Morrison (1997) observed opposing relations between a measure of locus of control (high scores indicated an internal locus, low scores an external locus) and Neuroticism and Conscientiousness. Her findings suggest a stronger relation between locus of control and the neuroticism measure ( $r=-.52$  for Neuroticism vs.  $r=.37$  for Conscientiousness).

Some personality theorists have even argued that Neuroticism and locus of control are indicators of a common construct measuring core self-evaluations. According to Judge and Bono (2001), perceptions of emotional stability and general well-being (Neuroticism) as well as an individual's beliefs about the causes of events in her or his life (Locus of Control) represent core self-evaluations or bottom-line evaluations held by individuals. Generalized self-efficacy, a component of the trait Conscientiousness, and self-esteem were also identified as core self-

evaluations. Meta-analysis results support this contention, as one higher order concept accounted for the relation among all four traits, and the individual traits were unable to predict additional variance in outcomes beyond that accounted for by the higher order construct (Judge, Erez, Bono, & Thoresen, 2002). The current findings suggest that the ERN/Ne may be a useful physiological measure for exploring this issue further, as opposite patterns of ERN/Ne activity were observed across motivational states for two of these personality domains.

#### *Specific or General Error Salience Effects?*

This investigation was an attempt to broaden current understanding regarding the ERN/Ne component by determining the specificity of the affective information. To understand how error processing occurs in our day-to-day lives, it is necessary to examine affective processing when more than one error can occur within the same context (and the incentives for avoiding each type of error are different). The pertinent question is whether motivational incentives induce a more vigilant state such that error salience is enhanced for all types of errors, or whether error salience only increases for the error type associated with the incentive. This is relevant to how error monitoring occurs in daily life because there are often several aspects of performance to monitor at the same time, and some aspects may hold more dire consequences than others. In the present investigation, this issue was addressed by examining the ERN/Ne for low and high salient errors in the unequal motivation conditions. A specific effect of error salience was predicted, as demonstrated by a condition by error type interaction, with larger ERN/Ne amplitudes expected for the more salient error type in each condition (i.e., FEs in the GFM condition and HEs in the GHM condition). The predicted interaction was observed, but not for the entire sample. Those scoring low on Conscientiousness and those scoring high on Neuroticism demonstrated amplitude differences in the ERN/Ne consistent with the incentive associated with each error type. It is important to keep in mind that the overall level of motivation (i.e., financial payoffs available for accurate performance) offered in the GFM and GHM conditions was equivalent, though incentives for finger and hand accuracy were not equal. Thus, evidence of ERN/Ne differences for these conditions indicates that the salience of each error (rather than the general motivational state) influenced ERN/Ne amplitudes. Therefore, although sensitivity to incentives may be dependent on underlying personality dispositions, the affective processes reflected in the ERN/Ne appear to operate in a very specific manner, reflecting our monitoring of errors selectively based on the incentives or consequences associated with each particular aspect of performance. This implies that the likely generator of the ERN/Ne in the anterior cingulate is able to keep distinct the incentives or penalties specifically associated with performance (see, e.g., the model of Holroyd & Coles, 2002).

#### *Unsupported Hypotheses and Possible Explanations*

Although the present findings demonstrate error salience effects for the ERN/Ne, not all of the motivational hypotheses were supported. The ERN/Ne amplitude was predicted to increase from the NM to the EQM condition due to the addition of accuracy incentives, but this motivational effect was not observed, even when the influence of personality traits was taken into account. The behavioral evidence was consistent with a motivational effect, as fewer errors were committed in the EQM condition relative to the NM condition. However, because the

NM condition was also the first testing condition, it is possible that some of the improvement was due to practice effects rather than increased motivation. Participants were given the chance to become familiar with the task prior to testing to reduce practice effects, but faster correct RTs in the GFM versus NM condition suggest that their ability to perform the task quickly and accurately may have been improving over time. Thus, one explanation for the absence of ERN/Ne amplitude differences between the NM and EQM conditions is that the monetary incentives in the EQM condition were simply not effective. However, it is not clear why the incentives in the EQM condition would not have a motivational impact when both the ERN/Ne and behavioral data for the unequal motivation conditions suggest that error salience was affected by monetary incentives.

An alternative explanation is that the NM condition was not an appropriate baseline measure because error salience was already elevated during this condition. This explanation is compatible with the ERN/Ne findings as there appeared to be a ceiling effect, with a large ERN/Ne in the NM condition that did not change much when incentives were added in the EQM condition. It may be that the first testing experience is more arousing and anxiety-provoking regardless of whether participants have practiced the task for a short time before testing. If error salience was already high due to a hyperaroused or more vigilant state, the addition of external incentives for accuracy may not have made much difference. Participants' subjective ratings suggest this may have been the case, as error awareness ratings were higher in the NM condition relative to the unequal motivation conditions, but not significantly different from the EQM condition. In addition, there was also evidence of a decline in the ERN/Ne amplitude from the first half to the second half of testing.

The findings presented by Luu et al. (2000) also suggest changes in affective behavior across the testing period, but the changes they noted were more dependent on personality. Luu et al. compared the ERN/Ne amplitude for each of the four 200-trial segments of their task while motivational aspects of the task (loss of points for slow and/or incorrect responses) remained constant. Relative to the first 200-trial block, they found decreases in the ERN/Ne for the remaining 600 trials, but only for those high in negative affect (NA). Also, unlike the present findings, the high NA group started with a larger ERN/Ne amplitude relative to the low NA group, who showed a more stable pattern. Based on these findings and the lack of interest in the task and dissatisfaction with performance reported by high NA participants, Luu et al. argued that these individuals tended to overengage initially, and then disengage from the task as time passes. Thus, while evidence from the present study illustrates the importance of personality for determining sensitivity to experimentally induced changes in motivation, Luu et al.'s findings suggest personality may also be important for predicting natural fluctuations in motivation or changes in internally driven motivation. Differences in the testing length and motivational incentives may also have contributed to these differences. For example, the longer testing period in the present study (2,080 vs. 800 trials) may explain why amplitude decline was more common in our sample. Furthermore, if Neuroticism and NA are closely related, continually changing incentives may have prevented the high Neuroticism group from disengaging more so than others, because of their demonstrated sensitivity to motivational changes. Regardless of subtle discrepancies, both findings indicate that it is important to be aware of natural fluctuations

in motivation that may alter error salience in ways unintended from the experimental procedure.

## Conclusions

The results from this investigation provide further evidence that affective processes are reflected in the ERN/Ne brain signal and also offer additional support for theories of anterior cingulate function that posit motivational and evaluative capacities to this

brain region. Furthermore, the findings demonstrated that quantitative changes in salience level are captured in the ERN/Ne component. These affective changes occur in a very specific manner, perhaps enabling more selective error monitoring based on the incentives or consequences associated with each particular aspect of performance. More importantly, these findings illustrate that to predict an individual's response to errors, it is necessary to account for motivational states as well as underlying personality dispositions that may influence sensitivity to motivational incentives.

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