

Research Report

The Devil You Know

Neuroticism Predicts Neural Response to Uncertainty

Jacob B. Hirsh and Michael Inzlicht

University of Toronto

ABSTRACT—*Individuals differ in the extent to which they respond negatively to uncertainty. Although some individuals feel little discomfort when facing the unknown, those high in neuroticism find it aversive. We examined neurophysiological responses to uncertainty using an event-related potential framework. Participants completed a time-estimation task while their neural activity was recorded via electroencephalography. The feedback-related negativity (FRN), an evoked potential that peaks approximately 250 ms after the receipt of feedback information, was examined under conditions of positive, negative, and uncertain feedback. The magnitude of these responses was then analyzed in relation to individual differences in neuroticism. As expected, a larger FRN was observed after negative feedback than after positive feedback for all participants. For individuals who scored highly on trait neuroticism, however, uncertain feedback produced a larger neural response than did negative feedback. These results are discussed in terms of affective responses to uncertainty among neurotic individuals.*

Uncertainty is the only certainty there is, and knowing how to live with insecurity is the only security. (Paulos, 2003, p. v)

A common finding in psychological research is that humans have an attentional bias toward negative information (e.g., Rozin & Royzman, 2001). Because threat information is presumably more important for survival than is nonthreat information, evolutionary theorists reason that such bias is an adaptive human trait. A parallel line of work has refined this view by demonstrating how individuals differ in the attention they give to emotional information. This work has shown that individuals high on trait neuroticism are most sensitive to threat (Rusting, 1998). Although this negativity bias is a commonly studied

phenomenon, it is usually contrasted with responses to positive or neutral information. What has been overlooked is how individuals differ in their responses to another class of motivationally relevant information: the unknown.

To appreciate the motivational relevance of the unknown, one need only examine research on the orienting response. This research emphasizes that the most important information in one's environment is that which is not yet understood (Sokolov, 2002). Successful adaptation, then, requires the formation of cognitive maps that continually incorporate new information. The orienting response facilitates this process by automatically allocating attentional resources toward unexpected events (Sokolov, 2002). Neuropsychologically, this process is supported by the septo-hippocampal comparator system (Vinogradova, 2001), which detects mismatches between expectations and observed outcomes. Incoming sensory information and cortical representations of the environment are compared in the hippocampus; when these comparisons produce incongruent information, the tonic inhibition of the reticular formation by hippocampal CA3 neurons is removed, heightening emotional arousal and rapidly focusing attention on the anomalous information. This process has been modeled as a fundamental source of anxiety (Gray & McNaughton, 2000), such that uncertainty about the environment can produce considerable discomfort.

In the literature on stress and coping, uncertainty is defined as the anticipation of a poorly defined threat (Monat, Averill, & Lazarus, 1972). Whereas exposure to familiar negative stimuli produces a well-defined threat, exposure to the unknown can be even more threatening because the potential danger is not clearly specified. Consequently, uncontrollable and unexpected threats produce greater anticipatory anxiety and physiological response than do controllable and predictable threats (Dickerson & Kemeny, 2004). Thus, individuals who know when to expect punishment show reduced physiological responses when that punishment occurs. In evolutionary terms, lack of knowledge about how to control or when to expect threats produces anxiety because it signifies that one's current cognitive map is not adequately adapted to the environment (Peterson, 1999). In order for the motivationally relevant parameters of the envi-

Address correspondence to Jacob B. Hirsh, Department of Psychology, Sidney Smith Hall, 100 St. George St., Toronto, Ontario, Canada M5S 3G3, e-mail: jacob.hirsh@utoronto.ca.

ronment to become well defined, attention must first be paid to that which is not understood. Here, we focus on how individuals vary in these responses to the unknown.

We are particularly interested in neuroticism, a personality trait associated with anxiety and emotional reactivity (Goldberg, 1993). Recent research has correlated neuroticism with self-reported intolerance of uncertainty (Berenbaum, Bredemeier, & Thompson, 2008). As might be expected given the link between uncertainty and anxiety, neurotic individuals experience greater distress than others when confronted with the unknown. What remains unclear, however, is whether neurotic individuals react more to uncertainty than to clear negative information, or vice versa. According to the negativity bias, negative information should elicit stronger reactions, but work on the orienting response suggests that uncertainty should produce the stronger response. We tested these opposing predictions by examining whether neurotic individuals are affected more strongly by negativity or uncertainty.

We also examined the neural systems underlying individual differences in response to uncertainty. Specifically, we looked at the feedback-related negativity (FRN), an event-related potential (ERP) implicated in error monitoring and feedback processing (Holroyd & Coles, 2002; Miltner, Braun, & Coles, 1997; Yeung, Botvinick, & Cohen, 2004). The FRN, a negative deflection in the ERP, peaks approximately 250 ms after the presentation of feedback information, and has been linked to activity in the anterior cingulate cortex (ACC). This brain region appears to interact with the septo-hippocampal comparator system to adapt behavioral responses as environmental circumstances change (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). Although the FRN tends to be more pronounced after negative feedback, it has also been observed following neutral feedback (e.g., Holroyd, Hajcak, & Larsen, 2006). The FRN was initially conceptualized as part of an error-monitoring and -correcting system (Holroyd & Coles, 2002; Luu et al., 2003; Miltner et al., 1997), but it has also been observed in the absence of response (Donkers, Nieuwenhuis, & Van Boxtel, 2005), leading some researchers to suggest that it reflects the subjective negative evaluation of self-relevant information, rather than an error signal per se (Gehring & Willoughby, 2002).

To examine individual differences in reactions to the unknown, we examined FRN magnitude after positive, negative, and uncertain feedback in a time-estimation task. The size of the FRN on these trials was then correlated with individual differences in trait neuroticism. We expected all participants to demonstrate a larger FRN to negative than to positive feedback. We also expected the response to uncertainty to be larger in more neurotic, compared to non-neurotic, individuals. Furthermore, we tested whether uncertainty or negativity exerts a stronger influence in neurotic individuals by comparing the amplitude of the FRNs associated with these two types of feedback. If fear of uncertainty exerts a stronger influence, a larger FRN would be expected to follow uncertain feedback. If the negativity bias

exerts a stronger influence, a larger FRN would be expected to follow negative feedback.

METHOD

Participants and Design

Participants were 41 right-handed introductory psychology students (27 females, 14 males; mean age = 18.9 years) from the University of Toronto Scarborough. Data from 4 subjects were excluded from analyses because of equipment malfunction.

Measures

Personality

We administered the Big Five Aspect Scales (DeYoung, Quilty, & Peterson, 2007), a reliable measure of the five major personality dimensions that has been validated against longer inventories such as the Revised NEO Personality Inventory. This questionnaire requires respondents to rate the extent to which each of 100 personality descriptions accurately reflects their own personalities.

Time-Estimation Task

We employed a time-estimation task to elicit the FRN (Miltner et al., 1997). A central fixation cross was presented for 250 ms, followed by a blank screen. Participants were required to press a response key when they believed that 1 s had passed since the appearance of the fixation cross. Visual performance feedback was provided 2 s after the initial fixation cue, resulting in an approximately 1-s interval between responses and feedback. This feedback stayed on-screen for 1 s and was followed by an intertrial interval varying between 1 and 2 s. Participants received instructions and 20 practice trials before the experimental phase. The task consisted of 168 trials, divided into four equal blocks that were separated by short breaks.

Participants received either positive (a plus sign) or negative (a minus sign) feedback depending on whether their response was within a predefined time window centered around 1 s after the appearance of the fixation cue. This time window, initially set at 100 ms, was made smaller after a correct response and larger after an incorrect response, such that the numbers of positive and negative feedback signals were approximately equal. Additionally, uninformative feedback (a question mark) was randomly presented on a third of the trials, so participants were uncertain about their performance. Each feedback type was presented an equal number of times to control for novelty effects. To ensure that the feedback had meaningful consequences, we informed participants that they would receive monetary bonuses for good performance. Such monetary incentives are effective motivators for undergraduate students, resulting in different electrophysiological responses to different categories of feedback (Holroyd et al., 2006). Participants

became familiar with the feedback signals during practice trials preceding the actual task.

Procedure

Participants were fitted with an electrode cap for electroencephalograph (EEG) recording and then completed a demographics questionnaire and the Big Five Aspect Scales. Continuous EEG was subsequently measured during the time-estimation task. Upon completion of the study, participants were awarded course credit and a \$5 bonus for performance on the time-estimation task.

Electrophysiological Recording and Processing

EEG was recorded from 32 Ag/AgCl sintered electrodes embedded in a stretch Lycra cap. Vertical eye movements (VEOG) were monitored via a supra- to suborbital bipolar montage. EEG and VEOG were digitized at 512 Hz using ASA acquisition hardware (Advanced Neuro Technology, Enschede, The Netherlands) with an average electrode reference and forehead ground. Continuous EEG was corrected for VEOG blink artifacts using the second-order blind identification (SOBI) procedure (Tang, Liu, & Sutherland, 2005). Frequencies below 1 Hz and above 15 Hz were digitally filtered. The signal was baseline-corrected by subtracting the average voltage occurring 500 to 400 ms before the feedback. Artifacts were automatically detected with thresholds of $-70 \mu\text{V}$ and $+70 \mu\text{V}$. ERP averages were created by feedback-locking the continuous EEG wave, with separate averages created for positive-, negative-, and uncertain-feedback trials. The FRN was quantified as the peak minimum deflection between 200 and 350 ms after feedback, and was examined at two midline electrode locations: Fz (frontal midline) and Cz (central midline).

RESULTS

We followed the methods of Holroyd and Krigolson (2007) and constructed two difference scores by subtracting the ERP on positive-feedback trials from the ERP on negative-feedback trials, and the ERP on positive-feedback trials from the ERP on uncertain-feedback trials. This technique minimizes the influence of other ERP components. We examined the scalp topography of the difference scores to ensure that we isolated the variance in the FRN amplitude and not another ERP component (such as the P300). Figure 1 illustrates the observed fronto-central distribution with a maximum negative deflection at Fz. Paired t tests comparing difference scores at Fz ($-5.3 \mu\text{V}$ for uncertain vs. positive feedback, $-4.7 \mu\text{V}$ for negative vs. positive feedback) and at the posterior midline (Pz, where the peak of the P300 is usually localized; $-0.5 \mu\text{V}$ for uncertain vs. positive feedback, $-3.4 \mu\text{V}$ for negative vs. positive feedback) revealed a significant difference between these sites, for both uncertain feedback, $t(37) = 5.44$, $p_{\text{rep}} = 1.00$, and negative

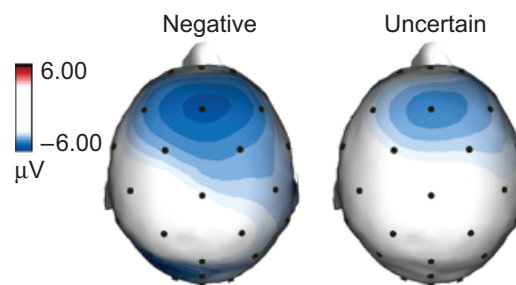


Fig. 1. Scalp topography of the feedback-related negativity (FRN) difference waves, quantified as the peak minimum deflections between 200 and 350 ms after feedback. FRN to negative feedback is shown on the left. FRN to uncertain feedback is shown on the right. The FRN following positive feedback was subtracted from both waves.

feedback, $t(37) = 3.50$, $p_{\text{rep}} = .95$. This result suggests that we indeed isolated the FRN.

To examine factors influencing FRN size, we conducted a repeated measures analysis of variance (ANOVA) with three midline electrode locations (Fz, Cz, and Pz) and the two feedback types (negative and uncertain) entered as within-subjects factors, and neuroticism entered as a covariate. Greenhouse-Geisser corrections were employed to correct for sphericity. As already noted, we had hypothesized that large FRNs in response to uncertain feedback would be associated with neuroticism. Feedback had a significant main effect, $F(1, 48.09) = 13.45$, $p_{\text{rep}} = .99$, $\eta_p^2 = .28$; also significant were two-way interactions between neuroticism and feedback, $F(1, 48.09) = 10.10$, $p_{\text{rep}} = .97$, $\eta_p^2 = .22$, and between feedback and electrode, $F(1.37, 48.09) = 10.10$, $p_{\text{rep}} = .99$, $\eta_p^2 = .22$, as well as the three-way interaction among neuroticism, feedback, and electrode, $F(1.37, 48.09) = 16.03$, $p_{\text{rep}} = .99$, $\eta_p^2 = .31$. Further analyses revealed that these effects are specific to neuroticism, and do not extend to any of the other personality traits. We conducted the same repeated measures ANOVA using each of the other Big Five traits, but found no main effects (all F s < 2.27), two-way interactions (all F s < 1.80), or three-way interactions (all F s < 2.07).

We examined the neuroticism parameter estimates to explore the nature of the significant three-way interaction. Following uncertain feedback, neuroticism demonstrated strong relationships with the FRN at Cz ($\beta = -.37$, $p_{\text{rep}} = .92$, $\eta_p^2 = .13$) and Fz ($\beta = -.46$, $p_{\text{rep}} = .97$, $\eta_p^2 = .21$); following negative feedback, there was no relationship between neuroticism and the FRN ($p_{\text{reps}} < .37$). After uncertain feedback, highly neurotic individuals had a larger FRN. Figure 2 displays the predicted FRN magnitudes at different levels of feedback and neuroticism and shows that the FRN in response to uncertain feedback was larger than the FRN in response to negative feedback for highly neurotic individuals. We tested this directly by employing a tertiary split, dividing the sample into groups with high, middle, and low neuroticism scores. At the low end of neuroticism, negative feedback produced a larger FRN than did uncertain feedback at Fz, $t(11) = -4.74$, $p_{\text{rep}} = .99$, and Cz, $t(11) =$

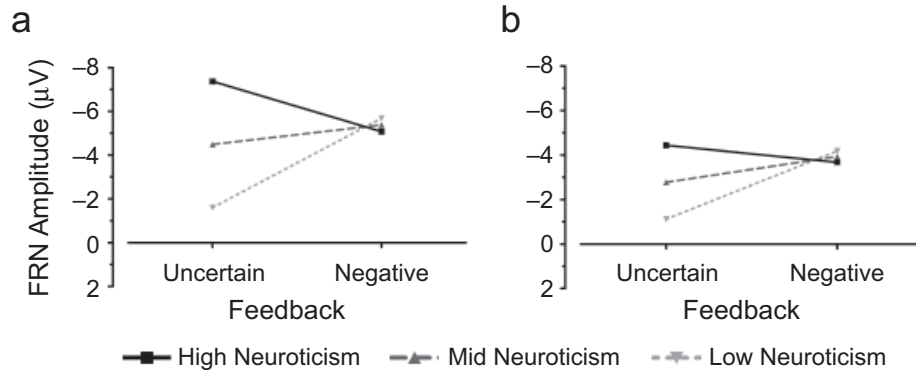


Fig. 2. Predicted feedback-related negativity (FRN) voltages after uncertain and negative feedback as a function of level of neuroticism, based on parameter estimates. Predictions are shown for electrode sites Fz (a) and Cz (b). The three levels of neuroticism were defined as follows: low = 1 SD below the mean; mid = mean; high = 1 SD above the mean. More negative voltage indicates a larger FRN.

-3.50, $p_{rep} = .97$. At the high end of neuroticism, however, uncertain feedback produced a larger FRN than did negative feedback at Fz, $t(11) = -2.36, p_{rep} = .90$, though the effect was nonsignificant at Cz, $t(11) = -1.04, p_{rep} = .63$. No significant differences were observed in the group with middle neuroticism

scores ($p_{reps} < .45$). Figure 3a presents the FRN waves at Fz for different feedback types and levels of neuroticism.

Interestingly, a significant linear trend for the neuroticism-by-electrode interaction emerged for uncertain feedback, such that moving along the midline from anterior to posterior

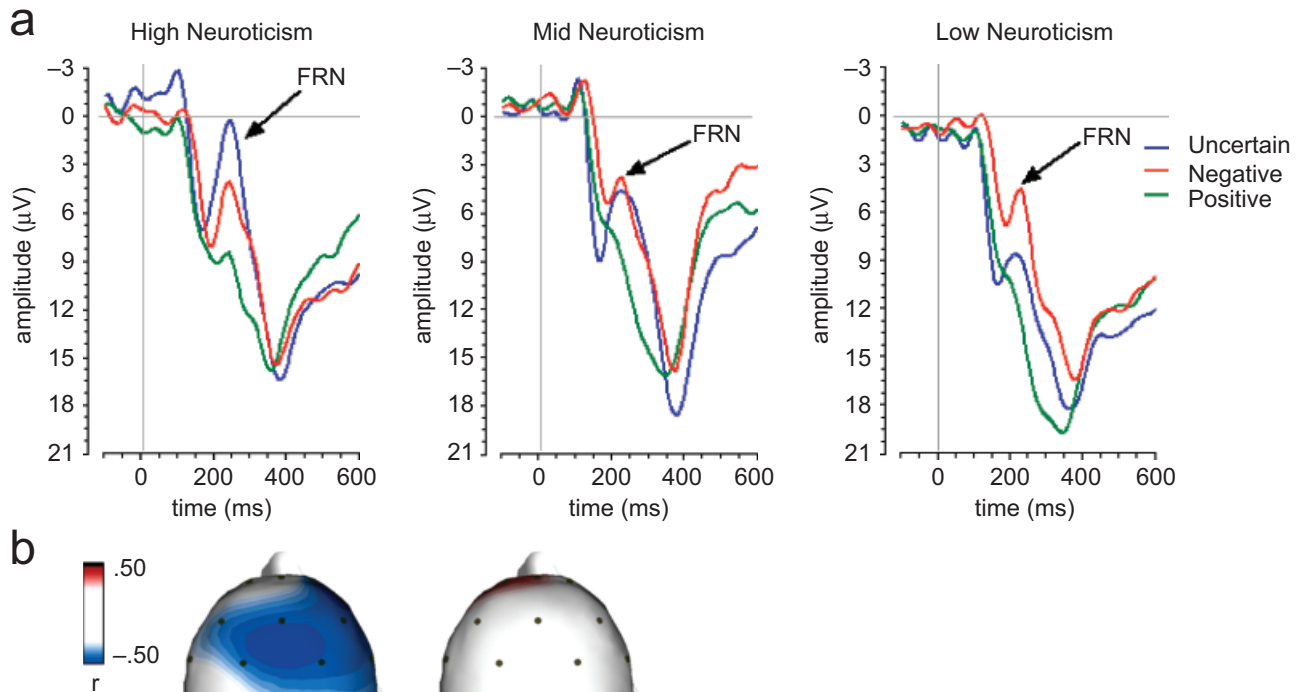


Fig. 3. Feedback-related negativity (FRN) waves at electrode site Fz (a) and head maps of the correlations between neuroticism and FRN magnitude (b). In (a), FRN waves associated with positive, negative, and uncertain feedback are shown separately for low-, middle-, and high-neuroticism groups, created by tertiary split. In (b), the map on the left illustrates the correlations between neuroticism and FRN magnitude in response to uncertain feedback, and the map on the right illustrates the correlations between neuroticism and FRN magnitude in response to negative feedback.

locations (Fz to Cz to Pz) linearly reduces the influence of neuroticism on the FRN, $F(1, 35) = 7.66, p_{\text{rep}} = .95, \eta_p^2 = .18$; the relationship between neuroticism and the FRN after uncertain feedback was thus most pronounced at fronto-central electrode sites. In contrast, there was no relationship between neuroticism and the FRN after negative feedback (see Fig. 3b).

DISCUSSION

Individuals differ in their responses to uncertainty (e.g., Sorrentino & Roney, 2000). We demonstrated that neural responses to uncertainty are related to the personality trait of neuroticism. Highly neurotic individuals produced a larger FRN in response to uncertain feedback than in response to negative feedback. This may explain why some research has shown that uninformative feedback can produce FRNs equal to those observed after negative feedback. In a series of five studies—one of them using the same time-estimation paradigm we used here—Holroyd et al. (2006) found that feedback that was either uncertain or intermediate (participants learned that they had neither lost nor gained money) elicited an FRN that was as large as that produced by negative feedback. Our findings are consistent with these previous results. Figures 2 and 3 suggest that negative and uncertain feedback will produce FRNs of similar magnitude at the middle range of neuroticism (as should be observed when results are averaged across normal-range participants). As neuroticism increases, however, the FRN amplitude following uncertain feedback becomes more pronounced. In contrast, we did not find a significant relationship between neuroticism and clearly negative feedback. Uncertainty thus appears to play a critical role in the relationship between neuroticism and the FRN, and we would not expect to see any relationship between neuroticism and the FRN to intermediate or neutral feedback. Further research is needed to test this prediction.

Figure 3 illustrates that the enhanced response to uncertainty in neurotics is observed primarily at fronto-central electrode locations. Given that rostral-ventral regions of the ACC are associated with affective processing (Bush, Luu, & Posner, 2000), our results suggest that enhanced responses to uncertainty in neurotics are primarily due to heightened emotional responding. Neurotic individuals thus demonstrated stronger affective responses to uncertainty than to clearly negative information (cf. Swann, Stein-Seroussi, & Giesler, 1992).

Rostral ACC activity during uncertainty has also been observed in functional magnetic resonance imaging (fMRI) experiments, which have shown that rostral ACC activity increases with greater uncertainty during a decision-making task and correlates with self-reported intolerance of uncertainty (Krain et al., 2006). Interestingly, rostral ACC activity during uncertainty has also been correlated with changes in autonomic arousal, which suggests that this brain region helps to increase physiological arousal when the potential threats of the unknown are

confronted (Critchley, Mathias, & Dolan, 2001). Neurotic individuals appear to appraise the unknown as more threatening than others do, and this appraisal may rally the appropriate physiological responses (cf. Tomaka, Blascovich, Kelsey, & Leitten, 1993).

Because we observed the FRN, on average, 250 ms after feedback ($SD = 40$ ms), the affective response to uncertainty appears to be a rapid, automatic process (Neely, 1977). In other words, neurotic individuals appear to preconsciously respond negatively to uncertainty. It is likely that rostral ACC activity during uncertainty is related to the amygdaloid complex, a region that is densely interconnected with the rostral ACC and associated with rapid processing of threat and uncertainty (Whalen, 1998, 2008). Heightened amygdala and rostral ACC activity is common to neuroticism and anxiety disorders (Haas, Omura, Constable, & Canli, 2007). The fronto-central negativities following uncertainty among neurotic individuals may thus be related to disinhibited amygdaloid function. Precise spatial localization of these processes, however, would require an fMRI approach, given the rough spatial resolution of EEG.

Whereas individuals low in neuroticism demonstrate a larger FRN after negative than after uncertain feedback, individuals higher in neuroticism react more strongly to uncertainty. This finding has important implications for human behavior, suggesting that some individuals would rather receive clear but negative information than endure the discomfort of uncertainty (even though the outcome might be positive). Our study suggests that uncertainty is difficult for these individuals because it evokes such a strong affective response. At high levels of neuroticism, then, people prefer the devil they know over the devil they do not know.

Acknowledgments—We thank Sonia Kang and Raymond Mar for their comments on earlier drafts of this manuscript. This research was supported by funds from the Spencer Foundation/National Academy of Education and by a Social Science and Humanities Research Council grant to Michael Inzlicht.

REFERENCES

- Berenbaum, H., Bredemeier, K., & Thompson, R.J. (2008). Intolerance of uncertainty: Exploring its dimensionality and associations with need for cognitive closure, psychopathology, and personality. *Journal of Anxiety Disorders, 22*, 117–125.
- Bush, G., Luu, P., & Posner, M.I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*, 215–222.
- Critchley, H.D., Mathias, C.J., & Dolan, R.J. (2001). Neural activity in the human brain relating to uncertainty and arousal during anticipation. *Neuron, 29*, 537–545.
- DeYoung, C.G., Quilty, L.C., & Peterson, J.B. (2007). Between facets and domains: Ten aspects of the Big Five. *Journal of Personality and Social Psychology, 93*, 880–896.

- Dickerson, S.S., & Kemeny, M.E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*, 355–391.
- Donkers, F.C.L., Nieuwenhuis, S., & Van Boxtel, G.J.M. (2005). Medial frontal negativities in the absence of responding. *Cognitive Brain Research*, *25*, 777–787.
- Gehring, W.J., & Willoughby, A.R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, *295*, 2279–2282.
- Goldberg, L.R. (1993). The structure of phenotypic personality traits. *American Psychologist*, *48*, 26–34.
- Gray, J.A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system*. Oxford, England: Oxford University Press.
- Haas, B.W., Omura, K., Constable, R.T., & Canli, T. (2007). Emotional conflict and neuroticism: Personality-dependent activation in the amygdala and subgenual anterior cingulate. *Behavioral Neuroscience*, *121*, 249–256.
- Holroyd, C.B., & Coles, M.G.H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*, 679–709.
- Holroyd, C.B., Hajcak, G., & Larsen, J.T. (2006). The good, the bad, and the neutral: Electrophysiological responses to feedback stimuli. *Brain Research*, *1105*, 93–101.
- Holroyd, C.B., & Krigolson, O.E. (2007). Reward prediction error signals associated with a modified time estimation task. *Psychophysiology*, *44*, 913–917.
- Krain, A.L., Hefton, S., Pine, D.S., Ernst, M., Castellanos, F.X., Klein, R.G., & Milham, M.P. (2006). An fMRI examination of developmental differences in the neural correlates of uncertainty and decision-making. *Journal of Child Psychology and Psychiatry*, *47*, 1023–1030.
- Luu, P., Tucker, D.M., Derryberry, D., Reed, M., & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science*, *14*, 47–53.
- Miltner, W.H.R., Braun, C.H., & Coles, M.G.H. (1997). Event-related brain potentials following incorrect feedback in a time-estimation task: Evidence for a 'generic' neural system for error-detection. *Journal of Cognitive Neuroscience*, *9*, 788–798.
- Monat, A., Averill, J.R., & Lazarus, R.S. (1972). Anticipatory stress and coping reactions under various conditions of uncertainty. *Journal of Personality and Social Psychology*, *24*, 237–253.
- Neely, J.H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*, 226–254.
- Peterson, J.B. (1999). *Maps of meaning: The architecture of belief*. New York: Routledge.
- Paulos, J.A. (2003). *A mathematician plays the stock market*. New York: Basic Books.
- Rozin, P., & Royzman, E.B. (2001). Negativity bias, negativity dominance, and contagion. *Personality and Social Psychology Review*, *5*, 296–320.
- Rusting, C.L. (1998). Personality, mood, and cognitive processing of emotional information: Three conceptual frameworks. *Psychological Bulletin*, *124*, 165–196.
- Sokolov, E.N. (2002). *The orienting response in information processing*. Mahwah, NJ: Erlbaum.
- Sorrentino, R.M., & Roney, C.J.R. (2000). *The uncertain mind: Individual differences in facing the unknown*. Philadelphia: Psychology Press.
- Swann, W.B., Stein-Seroussi, A., & Giesler, R.B. (1992). Why people self-verify. *Journal of Personality and Social Psychology*, *62*, 392–401.
- Tang, A.C., Liu, J.Y., & Sutherland, M.T. (2005). Recovery of correlated neuronal sources from EEG: The good and bad ways of using SOBI. *NeuroImage*, *28*, 507–519.
- Tomaka, J., Blascovich, J., Kelsey, R.M., & Leitten, C.L. (1993). Subjective, physiological, and behavioral effects of threat and challenge appraisal. *Journal of Personality and Social Psychology*, *65*, 248–260.
- Vinogradova, O.S. (2001). Hippocampus as comparator: Role of the two input and two output systems of the hippocampus in selection and registration of information. *Hippocampus*, *11*, 578–598.
- Whalen, P.J. (1998). Fear, vigilance, and ambiguity: Initial neuroimaging studies of the human amygdala. *Current Directions in Psychological Science*, *7*, 177–188.
- Whalen, P.J. (2008). The uncertainty of it all. *Trends in Cognitive Sciences*, *11*, 499–500.
- Yeung, N., Botvinick, M.M., & Cohen, J.D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review*, *111*, 931–959.

(RECEIVED 10/20/07; REVISION ACCEPTED 4/14/08)