Mistakes Pertaining to Undesired (relative to Desired) Self-Standards Elicit Immediate Enhanced Electrocortical Signals of Error Processing

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Abstract

Past research provides initial evidence that errors pertaining to undesired (vs. desired) self-standards are of greater motivational significance, but little is known about how quickly people recognize and respond to such errors. To examine immediate responses to errors pertaining to desired and undesired self-standards, we assessed event-related potentials (ERPs) while participants judged self-attributes as personally desirable or undesirable. No discernable differences emerged in ERPs associated with correct responses to undesired compared to desired self-standards. Error-related negativities (ERNs), shown in past work to index motivational significance, and Error Positivities (Pes), shown in past work to index post-error adjustment, were more pronounced when participants erroneously endorsed undesirable self-standards than when they erroneously failed to endorse desirable self-standards. These electrophysiological correlates of differences in the motivational significance of undesired vs. desired self-standards emerged within 400 msec of making an error, suggesting that the impact of these errors does not require extensive deliberation.

Keywords: self regulation; motivation; event-related potentials; desired and undesired selves

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Both positive selves (mental representations the type of person one desires to be; Higgins, 1987; Markus & Nurius, 1986) and negative selves (mental representations of the type of person one fears becoming; Carver, Lawrence, & Scheier, 1999; Markus & Nurius, 1986) act as important reference points in self-regulation. Missing opportunities to live up to desired self-standards and embodying undesired self-standards both require corrective action. However, given that approach- vs. avoidance-tendencies elicit distinct responses to positive and negative outcomes (Carver & White, 1994; Elliot, 2006; Higgins, 1998), errors pertaining to desired and undesired self-standards may be experienced differently. The present study examined whether differences in the motivational significance of mistakes pertaining to desired and undesired self-standards occur automatically, or, instead, require some delay and deliberation.

The Motivational Significance of Desired and Undesired Self-Standards

Research on regulatory focus theory (Higgins, 1998) suggests that people may experience errors pertaining to undesired outcomes as more motivationally significant than errors pertaining to desired outcomes. Regulatory focus theory posits the existence of two motivational foci: a promotion system oriented towards ideals and aspirations, and a prevention system oriented towards duties and responsibilities. The theory distinguishes between the presence of positive and negative outcomes (gains and losses), as well as the absence of positive and negative outcomes (non-gains and non-losses). A promotion-focus leads people to focus on the maximum they wish to achieve, whereas a prevention-focus leads people to focus on the bare necessities of goal-pursuit (Brendl & Higgins, 1996; Freitas, Liberman, Salovey, & Higgins, 2002). As a result, failure for a prevention-focused individual (i.e., a loss) should be more intense than failure for a promotion-focused individual (i.e., a non-gain). Supporting this prediction, experiences of failure for promotion- and prevention-focused individuals evoke distinct emotional responses, such that prevention-focused individuals report feeling greater levels of agitation, whereas promotion-focused individuals report feeling greater levels of dejection (Higgins, Shah, & Friedman, 1997; Higgins, Grant, & Shah, 1999; Idson et al., 2000).

Furthermore, when faced with experiences of failure, prevention-focused individuals are more likely to take corrective action than promotion-focused individuals, as evidenced, for example, by displaying increased effort, persistence and performance after failure (Idson & Higgins, 1999; Van Dijk & Kluger, 2011). Such findings may be explained, in part, through the assumption that goals for a promotion-focused individual are relatively substitutable, given that the pursuit of any ideal should offer a similar opportunity for attaining a gain. Conversely, for a prevention-focused individual, any missed opportunity should be of great motivational significance given that each duty is necessary (Freitas et al., 2002; Hughes, 2013). Taken together, such findings offer support for the prediction that errors pertaining to undesired self-standards (i.e., a loss) are experienced as more motivationally significant than are errors pertaining to desired self-standards (i.e., a non-gain).

Despite strong theoretical bases for doing so, surprisingly little research has assessed differences in the motivational significance associated with errors pertaining to desired and undesired self-standards. Moreover, the few relevant investigations have relied exclusively on correlational designs and individuals' self-reported affective experiences. Life satisfaction, for example, has been found to correlate more strongly with experiences of increasing distance from undesired self-standards than with experiences of decreasing distance from desired self-standards (Ogilvie, 1987). In a related vein, experiencing agitation-related emotions correlates more strongly with perceived distance to feared selves (the person one fears becoming; Oyserman & Marcus, 1990) than to ought selves (the person one has a responsibility to be; see Higgins, 1987), as found by Carver, Lawrence, and Scheier (1999) and replicated conceptually by Heppen and Ogilvie (2003).

Converging evidence thus suggests that failing to avoid undesired self-standards evokes a greater affective response than does successfully embodying desired self-standards, but the findings' observational nature poses notable limitations on the conclusions that may be drawn from such work. Importantly, in investigating the relation between affective experiences and perceived distance to different self-standards, both Carver and colleagues (1999) and Heppen and Ogilvie (2003) used retrospective measures of affect (i.e., participants reported how they felt over the past several days). Such measures are prone to duration neglect (i.e., a tendency to focus on the highest intensity experiences, and to fail to account accurately for the amount of time that affect was experienced; Hedges, Jandorf, & Stone, 1985) and to recency effects (i.e., a tendency to form judgments about affect based on more recent experiences; Robinson & Clore, 2002).

Accordingly, although past research provides some initial evidence that errors pertaining to undesired (vs. desired) self-standards are of greater motivational significance, little is known about *when* differences in motivational significance emerge. That is, it remains an open question whether errors pertaining to undesired (vs. desired) self-standards are automatically recognized as more motivationally significant, or, instead, whether they require some degree of deliberation. To address this question, the present study aimed to: 1) provide a more direct assessment of responses to errors related to desired and undesired self-standards, and to 2) clarify when differences in the motivational significance of errors pertaining to various self-standards emerge. To address these goals, the present study focused on two well-validated event-related potentials

(ERPs) associated with making errors: the error related negativity (ERN) and the error positivity (Pe). In the context of the present research, ERPs are a useful tool because they allow for an immediate assessment of motivational significance and post-error adjustments.

The ERN and Pe

The ERN is a negative deflection in the ongoing electroencephalogram; it is characterized by a fronto-central distribution, it typically peaks within 100 msec of the recording of an incorrect response, and it is considered an early indicator of general error-processing (Gehring, Goss, Coles, & Meyer, 1993; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991). The ERN has been observed across studies that vary in both task difficulty (Falkenstein et al. 2000; Hoffmann and Falkenstein, 2010; Mathewson, Dywan, & Segalowitz, 2005; Pailing and Segalowitz, 2004a), and response modalities (Bernstein et al. 1995; Holroyd et al. 1998; Nieuwenhuis, Ridderinkhof, Blom, Band & Kok, 2001; Van't Ent & Apkarian, 1999), suggesting that the ERN reflects a general error-processing system that is not modality specific. Supporting the reliability of the ERN, previous studies have found that the ERN has acceptable test-retest reliability (Segalowitz et al. 2010) even over the course of 2 years (Weinberg & Hajack, 2011).

Whereas earlier models of the ERN emphasized its role in conflict and error detection (Holroyd & Coles, 2002; Yeung, Botvinick, & Cohen, 2004), recent research indicates that the ERN reflects motivational and affective responses to errors (Bartholow, Henry, Lust, Saults, & Wood, 2012; Hajcak, McDonald, & Simons, 2003; Luu, Collines, & Tucker, 2000; Pailing & Segalowitz, 2004b). In line with this view, a number of motivational factors modulate the amplitude of the ERN. For example, ERN amplitude is larger when correct responses on a task are associated with monetary reward (Chiu & Deldin, 2007; Hajcak, Moser, Yeung, & Simons, 2005a), when task instructions emphasize accuracy over speed (Falkenstein, Hoormann, Christ &

Hohnsbein, 2000; Gehring et al. 1993), when participants' performance is evaluated by others (Hajcak et al, 2005; Kim et al., 2005), and when individuals are concerned about making specific errors (such as those connoting racial prejudices; Amodio, Devine, & Harmon-Jones, 2008). Furthermore, ERN amplitude increases as the magnitude of an error increases, as assessed through the discrepancy between a participant's response and a given target on visual-spatial tasks (Vocat, Pourtois, & Vuilleumier, 2011). Vocat and colleagues (2011) have interpreted this finding as suggesting that, rather than reflecting an all-or-nothing response, the ERN is sensitive to the severity of an error. Converging evidence suggests, then, that the ERN is suitable as a physiological indicator of the motivational significance associated with errors (for a review, see Weinberg, Riesel, & Hajcak, 2012).

The Pe is a positive deflection that typically peaks shortly after the ERN, between 100 to 400 msec after an incorrect response (Falkenstein et al., 1991; Falkenstein, Hohnsbein & Hoormann, 1995). Although both the Pe and the ERN relate to making errors, the ERN and Pe appear to operate through separate neural substrates in the cingulate cortex and likely reflect distinct aspects of error-processing (Falkenstein et al., 2000; Nieuwenhuis et al., 2001; Vocat, Pourtois, & Vuilleumier, 2008). Supporting the view that the ERN and Pe capture different aspects of error-processing, previous research has found that the ERN and Pe relate to different motivational variables, with the ERN relating positively to state anxiety, and the Pe relating positively to the improvement of response times across time (Vocat et al., 2008). Further support for this view comes from research indicating that Pe amplitude, more so than ERN amplitude, is less pronounced when an individual is unaware of having made a mistake (Endrass, Reuter & Kathmann, 2007; Nieuwenhuis, et al., 2001). Such findings support the view that the Pe can be assumed to reflect the conscious awareness of the need for corrective action (Falkenstein et al., 2000; Nieuwenhuis, et al., 2001) and the mobilization of resources to mount such action (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005).

The Present Study

The present study examined whether the magnitude of ERN and Pe responses would vary as a function of whether participants committed errors pertaining to desired relative to undesired self-standards. In light of our above reasoning regarding the motivational importance of mistakes pertaining to desired and undesired self-standards, and in light of the above-reviewed evidence of the sensitivity of the ERN to the motivational significance of errors, we hypothesized that errors pertaining to undesired self-standards would elicit higher-amplitude ERN responses than would errors pertaining to desired self-standards. Additionally, consistent with the above-reviewed evidence that a concern with negative outcomes (i.e., a prevention focus) facilitates persistence in performance after failure relative to a concern with positive outcomes (i.e., promotion focus; Idson & Higgins, 1999; Van Dijk & Kluger, 2011), and evidence that the Pe reflects the mobilization of resources to take corrective action following errors (Overbeek et al., 2005), we hypothesized that errors pertaining to undesired self-standards would elicit higher-amplitude Pe responses than would errors pertaining to desired self-standards.

To address these questions, we administered to participants purported assessments of their unconscious self-concepts, in which participants indicated whether or not they wanted to possess generally desirable and undesirable attributes. Expecting each attribute to be replaced eventually by a different attribute, participants attempted to respond quickly, before any such replacement occurred. In this way, we were able to examine the amplitude of ERN and Pe responses when participants correctly and incorrectly responded to desirable and undesirable self-standards. This task required participants to shift between making judgments about whether they wanted to possess negative or positive self-attributes. Given the flexible nature of this task, this task is not an experimental manipulation of focusing on attaining positives (e.g., a promotion focus) or avoiding negative outcomes (e.g., a prevention focus). Instead, this task assessed people's continuous responses to making errors as they encountered opportunities to endorse or reject a variety of desired and undesired self-standards.

Methods

Participants

Twenty four undergraduates (11 males), aged 17-36 (M = 19.71), participated in exchange for course credit. Due to excessive EEG artifact (widespread skin potentials), data from one additional participant could not be analyzed. Our planned sample size was a minimum of 20 participants, to be collected within a single semester. We began data analyses only after data collection was terminated.

To determine an appropriate sample size for the present study we drew on past studies assessing experimentally-manipulated differences in the ERN. Past studies using within-subjects designs include sample sizes of 18 (Pailing & Segalowitz, 2004a), 20 (Larson, Perlstein, Stiggle-Kaufman, Kelly, & Dotson, 2006), 22 (Wiswede, Münte, Goschke, & Rüsseler, 2009), and 25 (Endrass, Reuter, & Kathmann, 2007). Based on those previous findings, we sought a priori to acquire usable data from at least 20 participants across a single semester.

Materials

Twenty positive trait words (witty, smart, clean, happy, loyal, kind, active, bright, clever, talented, likable, popular, truthful, skilled, logical, capable, ethical, helpful, good, sincere) and twenty negative trait words (dull, weak, cruel, phony, stupid, greedy, vulgar, boring, hostile, gloomy, stingy, clumsy, selfish, helpless, abusive, jealous, fake, annoying, hateful, cowardly) served as the desirable and undesirable self-attributes, respectively. Each averaging 6.15 letters per word, the two lists were drawn primarily from Anderson (1968). It is important to note that an alternative interpretation of our anticipated results would be possible if the undesired attributes used in this experiment were perceived as more informative than were the desired attributes. If that were true, more intense responses to erroneously endorsing the undesired attributes (relative to erroneously failing to endorse the desirable attributes) could be predicted on the basis of attribute informativeness alone, given that people respond most strongly to highly informative and meaningful failures, criticisms, and experiences (Pelham, 1991).

Addressing this issue, an additional sample of 25 undergraduates rated, in randomized orders, the 40 attributes used in this study for the extent to which "knowing that someone did or did not possess each attribute would tell you a lot about that person" (1 = very uninformative; 7 = very informative). Minimizing the likelihood that below-reported ERN and Pe results reflect viewing the undesirable attributes as more informative than the desirable attributes, participants rated the 20 undesirable attributes (α = .92) as non-significantly *less* informative (M = 4.22) than the 20 desirable attributes (α = .87; M = 4.80; t = 1.92, p = .067, d = .57).

Procedure

In a sound-attenuating chamber, participants sat approximately 90 cm from the CRT monitor on which experimental stimuli appeared (approximately 6 x 1 cm in black on a light gray background) and responded using the left and right thumb. The task was described as a measure of participants' unconsciously held self-views (with counterbalanced response mappings indicated in parentheses): "[On each trial of this] Unconscious Self-Views Task, you'll see a word, like 'courageous.' Click the LEFT (RIGHT) button if you WANT to be this way, or click the RIGHT (LEFT) button if you do NOT want to be this way. The hard part is that every word will disappear after variable amounts of time and be replaced by a different word. If the word changes before you respond, you should still respond to the FIRST word." On the critical 60% of trials for which the presently reported data analyses were conducted, the first attribute (either desirable or undesirable, in equal proportions) remained visible until a response registered.

On the remaining trials, which were included to encourage participants to respond quickly and hence commit sufficient errors to allow analyzing the ERN, the first attribute was replaced by a different attribute (either desirable or undesirable, in equal proportions) either (a) after 320 msec; or (b) when triggered by the participant's response and then remaining visible for 160 msec. Separated by intervals varying randomly between 600-950 msec, trials began with a 200-msec fixation cue (".") and were selected for presentation randomly without replacement (with the item pool replenished every 20 trials). Following two 20-trial practice blocks, there were 1000 trials across 10 blocks, with performance feedback (on accuracy and latency) provided after each block. Participants lastly completed Rosenberg's (1979) 10-item self-esteem measure. In sum, participants completed a total of 1000 trials and saw each attribute 25 times. All subsequent ERP and response time analyses were conducted on the critical 600 trials, during which each attribute was presented a total of 15 times.

Electrophysiological Recording

The EEG was recorded continuously via a 32-channel electrode cap (Neuroscan Inc., Sterling USA), using a fronto-central electrode as ground and electronically linked mastoid electrodes as reference. The horizontal electrooculogram (EOG) was monitored from electrodes at the outer canthi of the eyes, and the vertical EOG was monitored from electrodes above and below the orbital region of the left eye. Impedances for all electrodes were kept below 10 KΩ.

The EEG and EOG signals were digitized at 500 Hz and amplified with a gain of 1000. The filter bandpass was .01-30 Hz.

ERP Analysis

Results are drawn from response-locked epochs beginning 100 msec before each response was recorded and concluding 900 msec thereafter. Mean amplitude during the first 100 msec of each epoch was subtracted from remaining timepoints. To address EEG artifact, independent component analysis (ICA), accomplished via the Runica function of EEGlab (Delorme & Makeig, 2004), was used in two steps. First, through visual inspection and an initial ICA, epochs containing extreme non-stereotypic artifacts were identified and removed (4.40% of all trials). Via a second ICA, components reflecting eye movements, muscle-related activity, and channel-specific line noise were identified and subtracted. Following ICA-based corrections, any epochs with EEG voltages exceeding +/-75 microvolts (µV) were rejected (for two participants, who otherwise would have lost a significantly higher proportion of trials than other participants, a +/-100 µV threshold was used at this step), resulting in exclusion of 1.24% of remaining trials. The ERN was defined as mean amplitude between 0 and 100 msec following the response, and the Pe was defined as mean amplitude between 100 to 400 msec following the response. Prior to statistical analysis, data from the three electrodes nearest the midline were placed into groups centered at FZ (FZ, F3, F4), FCZ (FCZ, FC3, FC4), CZ (CZ, C3, C4), CPZ (CPZ, CP3, CP4), and PZ (PZ, P3, P4). In cases of a bad electrode (total N = 3 bad electrodes across the 24 participants), data from the participant's remaining electrodes in each grouping were used. Comparisons exceeding two within-subjects levels report Greenhouse and Geisser's (1959) corrected p-values.

Results

Attribute Desirability and Response Times

Mean attribute endorsement (coded 0 or 1) was .87 (*SD* = .07) for desirable attributes and .13 (*SD* = .09) for undesirable attributes. These endorsement rates show that participants indicated wanting to possess the desirable attributes to a similar degree of extremity as they indicated not wanting to possess the undesirable attributes, yielding $F = 0.10$, $p > .750$, when comparing their average distances from .50 to one another. Accordingly, in subsequent analyses, “I want to be this way” responses to desirable and undesirable attributes respectively were coded as correct and incorrect, and “I don’t want to be this way” responses to desirable and undesirable attributes respectively were coded as incorrect and correct.

Response times were limited to response between 200 and 1500 mseconds, which led to the exclusion of 1.02% of trials. A repeated-measures ANOVA revealed that participants were faster to endorse desirable attributes (*M* = 547.72 msec, *SD* = 72.22) than to reject undesirable attributes (*M* = 570.23 msec, *SD* = 58.88), $F(1, 23) = 8.61$, $p = .008$, $\eta_p^2 = .27$. It is important to note that these differences in response time are independent of the ERP effects reported below, given that all ERP waveforms were time-locked to participants’ responses, not to stimulus presentations.

ERN Amplitude Modulation

Mean amplitudes during the ERN window were analyzed in a 2 (Response Accuracy: error vs. correct) x 2 (Attribute Desirability: desirable vs. undesirable) x 5 (Electrode Region: F, FC, C, CP, or P) repeated-measures ANOVA. There was a significant effect of Response Accuracy, $F(1, 23) = 24.13$, $p < .001$, $\eta_p^2 = .51$,which was moderated by Electrode Group, $F(4, 92) = 24.22$, $p < .001$, $\eta_p^2 = .51$, reflecting the typical fronto-central distribution of the ERN. Most importantly, as illustrated in Figure 1, there was a significant interaction between Response

Accuracy and Attribute Desirability, $F(1, 23) = 8.31$, $p = .008$, $\eta_p^2 = .27$, which was not moderated further by Electrode Group, $F(4, 92) = 0.95$, $p = .440$, $\eta_p^2 = .04$. As reported in Table 1, amplitude during the ERN window was more negative for undesirable attributes than for desirable attributes on error trials, with this difference statistically significant at electrode groups centered at FZ, FCZ, CZ, and CPZ (ts $\geq$ 2.31, ps $\leq$ .030, ds $\geq$ .99) but not PZ ($t = 0.52$). On correct trials, attribute desirability did not significantly impact amplitude during the ERN window at any electrode groups.

Pe Amplitude Modulation

Mean amplitudes during the Pe window were analyzed in a 2 (Response Accuracy: error vs. correct) x 2 (Attribute Desirability: desirable vs. undesirable) x 5 (Electrode Region: F, FC, C, CP, or P) repeated-measures ANOVA. There was a significant effect of Response Accuracy, $F(1, 23) = 77.72$, $p < .001$, $\eta_p^2 = .77$, which was moderated by electrode group, $F(4, 92) = 40.88$, $p < .001$, $\eta_p^2 = .64$, reflecting the typical centro-parietal distribution of the Pe. More importantly, there was a significant interaction between Response Accuracy and Attribute Desirability, $F(1, 23) = 4.82$, $p = .039$, $\eta_p^2 = .17$, which was not moderated further by Electrode Group, $F(4, 92) = 0.12$, $p = .97$, $\eta_p^2 < .01$. As reported in Table 1, amplitude during the Pe window was more positive for undesirable attributes than for desirable attributes on error trials, with this difference statistically significant at all electrode group locations (ts $\geq$ 2.39, ps $\leq$ .025, ds $\geq$ 1.02). On correct trials, attribute desirability did not impact Pe amplitude at most electrode groups (ts $\leq$ 1.78, ps $\geq$ .088, ds < .76), excepting at electrodes centered at PZ ($t = 2.33$, $p = .029$, $d = .99$).

Comparing the First and Second Half of Trials

To address potential practice effects given the large number of trials in this study, we also examined whether the relationship between response accuracy and attribute desirability varied between the trials occurring in the first and second half of the study. Mean ERN and mean Pe amplitude were analyzed separately in 2 (Time: First Half vs. Second Half of Trials) x 2 (Response Accuracy: error vs. correct) x 2 (Attribute Desirability: desirable vs. undesirable) x 5 (Electrode Region: F, FC, C, CP, or P) repeated-measures ANOVAs. As illustrated in Figure 2, time did not moderate the interaction between response accuracy and attribute desirability for ERN amplitude, F (1, 23) = .24, p = .629, $\eta_p^2 < .01$, or Pe amplitude, F (1, 23) = .10, p = .759, $\eta_p^2 < .01$.

Error Rates by Attribute Desirability and Item

We expected that most participants would intend to endorse the positive attributes and to reject the negative attributes. However, it is possible that some participants may have intended to reject some positive attributes and to endorse some negative attributes. To examine any potential implications of this possibility for our conclusions, we first tested whether there was a difference in how frequently positive attributes were endorsed and negative attributes were rejected. There was no difference in accuracy rates between the desirable (M = .87, SD = .07) and undesirable attributes (M = .88, SD = .09), F (1, 23) = .30, p = .587, $\eta_p^2 < .01$. This analysis suggests that the observed differences in ERN and Pe amplitude do not appear attributable to differences in the frequency with which participants endorsed the desirable attributes and rejected the undesirable attributes. Second, we examined whether there were any participants who made more than 50% errors for specific attributes. Fifteen participants had less than 50% errors for all attributes (62.50%), and the remaining participants had more than 50% errors on 1 (n = 5), 2 (n = 2), 3 (n = 1), or 4 attributes (n = 1). In the most extreme case, then, for the participant with high error rates on 4 attributes, 90% of his or her responses (i.e., 36/40) were to desirable attributes he or she generally endorsed and to undesirable attributes he or she generally rejected.[1]

Discussion

The present findings suggest immediate differences in the motivational importance and post-error adjustment associated with errors pertaining to desired and undesired self-standards. Few discernable differences emerged in event-related potentials associated with correct responses to undesired compared to desired self-standards. Higher-amplitude ERN and Pe responses emerged when participants erroneously endorsed undesirable self-standards than when they erroneously failed to endorse desirable self-standards. One contribution of the present research is that it demonstrates the immediacy with which differences in the motivational significance between desired vs. undesired self-standards emerge. Whereas past studies have drawn on self-reports of affective experiences to assess the motivational significance of desired and undesired self-standards (e.g., Carver et al., 1999), the present results indicated that errors pertaining to undesired self-standards are perceived as more motivationally significant and recruit greater post-error adjustments within 400 msec of making an error. The speed with which errors pertaining to self-standards are processed suggests that the impact of these errors does not require extensive deliberation.

Whether a response is automatic, or instead requires some degree of deliberation, is a topic of longstanding interest in psychology. One seminal example of this includes the debate between Lazarus (1984) and Zajonc (1984) regarding the nature of the relationship between cognition and affect. In this vein, we compare the present findings to research on regret. Regret is a negative emotion that arises from drawing a comparison between what has occurred and what might have occurred (Bell, 1982; Loomes & Sugden, 1982), and it is stronger in situations in which one feels personally responsible for having caused a negative outcome (Zeelenberg, van Dijk, & Manstead, 1998). Regret is an emotional experience, then, that requires some degree of temporal delay and evaluation. Conversely, in the present study, errors pertaining to undesired self-standards were of greater motivational significance and received greater post-error processing almost instantly. As reviewed previously, past studies have found that people report greater negative emotions, such as guilt, when they perceive themselves as close to embodying undesired self-standards (Carver et al., 1999; Heppen & Ogilvie, 2003). Extending those findings, the present research is the first to demonstrate the immediate, non-deliberative nature with which such judgments about the self may be processed. By incorporating an online measure of error-processing, the present study allows for a novel assessment of people's automatic responses to failing to meet their self-standards at a level of analysis that was not possible in past studies.

A second contribution of the present research is that it highlights the extent to which people are able to adapt flexibly to maximal and minimal goals encountered successively across time. A hallmark of regulatory focus theory (Higgins, 1998) is that strategic orientations toward eagerness or vigilance will carry over across separate events to influence general sensitivity to nurturance- and safety-related information, as when generating eagerness versus vigilance strategies moderates the impact of familiarity cues on aesthetic judgments (Freitas, Azizian, Travers, & Berry, 2005). Whereas past research has highlighted the enduring nature of broad motivational orientations, relatively few studies have assessed the ways in which people switch between processing information that varies in its motivational content and significance. The present experiment, by randomly interspersing desired and undesired self-standards, shows that people are able to adapt flexibly to maximal and minimal goals encountered successively across time. The apparent independence of broad motivational orientations suggests that the present findings also may apply to minimal and maximal goals considered simultaneously. For example, when facing conflict between desired and undesired self-standards (e.g., trying to be honest while avoiding being cruel when critiquing others), the imperatives of undesired self-standards may take precedence only when failure appears subjectively probable, given the present evidence of heightened significance of failure, but not success, pertaining to undesired self-standards

There are several limitations of this study. First, as is typical in studies assessing the ERN (for a review, see Hajcak, 2012), the number of errors made by each participant was not under experimental control. The task was designed to encourage participants to respond quickly, to increase the likelihood of making some errors, but this led to some variability in the frequency of errors across participants. Second, the experimental task required participants to complete a large number of trials, and each attribute was repeated numerous times. Although a large number of trials is necessary for assessing ERPs, a disadvantage of this procedure is that participants can become fatigued and/or prone to practice effects. We found that participants had greater ERN and Pe amplitude responses after erroneously endorsing an undesirable attribute in both the first and second half of trials, suggesting that fatigue and practice effects did not have a notable impact on the primary findings. Third, we did not include a pre-measure of participants' actual desirability to embody the 40 attributes prior to data analysis. Future work including such a measure could provide an objective index for distinguishing errors from non-errors.

Future research also may investigate whether the increase in cognitive resources recruited by errors pertaining to undesired self-standards, as reflected by changes in Pe amplitude, interferes with subsequent, unrelated actions. Given that the present study included valenced self-referential items on each trial, this study was not designed to test this question; however, future research that includes neutral items, in addition to valenced items, may examine whether errors pertaining to undesired self-standards lead people to slow down on subsequent trials more so than errors pertaining to desired self-standards. To the extent that goals pertaining to undesired self-standards are perceived as less substitutable than are goals pertaining to desired self-standards (Freitas et al., 2002; Hughes, 2013), one may become preoccupied with understanding and attempting to prevent future errors pertaining to undesired self-standards more so than for errors pertaining to desired self-standards.

Furthermore, whereas numerous studies have investigated the extent to which various affective and motivational factors relate to the ERN (e.g., high negative affect; Hajcak, McDonald & Simons, 2004), relatively less is known about personality correlates of the Pe. For example, future research may examine whether relationships between Pe amplitude and rumination may help to explain how errors pertaining to undesired self-standards impact future action control and self-regulation. Finally, whereas the present research focused on differences in the motivational significance of erroneous responses, future research may investigate when differences in motivational significance emerge in response to correctly endorsing desirable self-attributes, and correctly rejecting undesirable self-attributes. Based on research indicating that gains are more rewarding than non-losses (Idson et al., 2000), components such as the P3 may be well-suited for discerning when differences in cognitive processing emerge for correct responses to desired and undesired self-standards.

Finally, the present study also may provide further insight into the predictions of regulatory focus theory for different types of emotions associated with prevention and promotion failures. Several studies have indicated that promotion failure produces dejection-related emotions, whereas prevention failure produces agitation-related emotions (Higgins, 1998; Higgins et al., 1999; Higgins et al., 1997; Idson et al., 2000). To account for this distinction, previous research has proposed that the pain of failure in a prevention focus increases vigilance, and that this vigilance is experienced as agitation-related emotions (Idson et al., 2000). Future research may examine whether ERN responses mediate the relation between regulatory focus and failure-related affective experiences. Such a prediction is consistent with other research in which states of vigilance are characterized by a higher ERN response (e.g., when correct responses on a task are associated with monetary reward, Chiu & Deldin, 2007; Hajcak et al., 2005). Future research that investigates how individuals use self-guides and affective cues to guide action, while simultaneously assessing the brain-mediated correlates of such phenomena, may facilitate the continuing refinement of models of interactions between motivation, cognition and self-regulation.

Footnotes

[1]We computed the same repeated-measures ANOVAs for ERN and PE amplitude reported above without the two participants who had high errors rates on 4 attributes and 3 attributes (i.e., the two most extreme cases), respectively. Without these two participants, there remained a significant response accuracy by attribute desirability interaction for ERN amplitude, F (1, 21) = 5.94, p = .024, η_p^2 = .22, and Pe amplitude, F (1, 21) = 6.82, p = .016, η_p^2 = .25.

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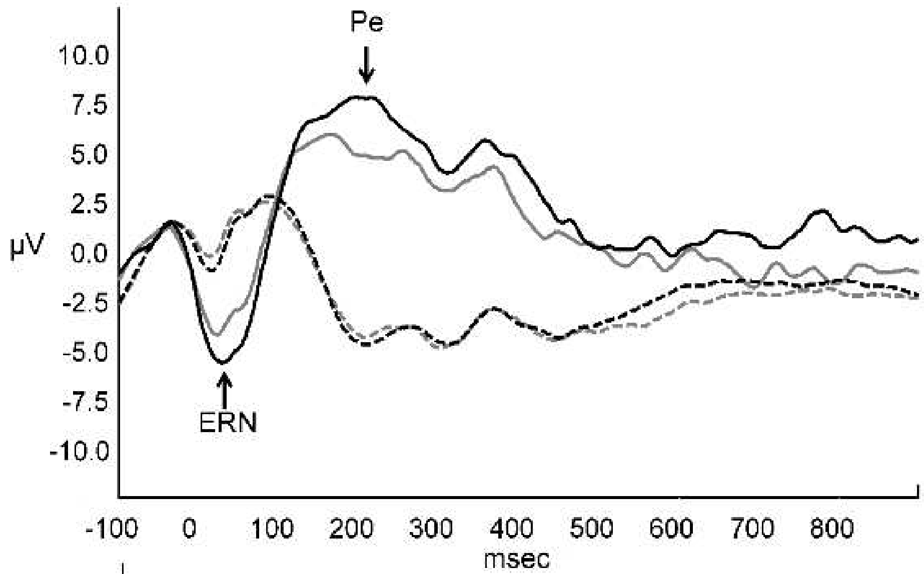
Table 1. Mean (and *SD*) amplitudes during ERN window (0 – 100 msec) and Pe window (100 – 400 msec), for event-related potentials response-locked to erroneously endorsing undesirable self-attributes (Endorse Neg.), erroneously rejecting desirable self-attributes (Reject Pos.), correctly rejecting undesirable self-attributes (Reject Neg.), and correctly endorsing desirable self-attributes (Endorse Pos.).

Note. Means and standard deviations are reported in microvolts (µV).

	Reject Neg.		Endorse Neg.		Endorse Pos.		Reject Pos.	
	ERN	Pe	ERN	Pe	ERN	Pe	ERN	Pe
Electrode Group								
Frontal (F3, F4, FZ)	1.23 (2.13)	-.81 (4.54)	-1.46 (2.51)	3.69 (3.70)	1.25 (2.53)	-0.69 (4.47)	-0.58 (1.72)	2.77 (3.37)
Fronto-central (FC3, FC4, FCZ)	1.27 (2.36)	-2.51 (5.01)	-2.19 (2.89)	4.64 (3.88)	1.32 (2.73)	-2.53 (4.64)	-1.07 (1.83)	3.36 (3.33)
Central (C3, C4, CPZ)	1.31 (2.29)	-4.15 (4.74)	-2.17 (2.65)	4.30 (4.11)	1.06 (2.71)	-4.53 (4.32)	-0.94 (1.93)	2.59 (3.29)
Centro-Parietal (CP3, CP4, CPZ)	0.58 (2.14)	-5.58 (4.69)	-2.08 (2.34)	2.99 (4.10)	0.16 (2.49)	-6.18 (4.40)	-0.99 (2.05)	1.17 (3.12)
Parietal (P3, P4, PZ)	-0.28 (2.00)	-6.38 (4.35)	-1.95 (1.98)	1.89 (3.96)	-0.75 (2.30)	-7.12 (4.33)	-1.16 (2.11)	.01 (3.03)



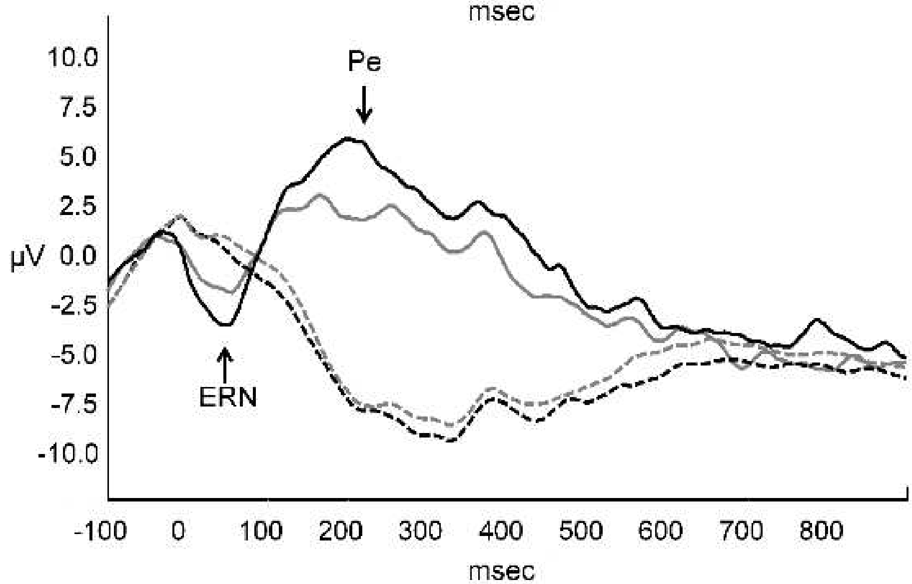


Figure 1. Event-related potentials at electrode FCZ (top) and CPZ (bottom) response-locked to erroneously endorsing undesirable self-attributes (solid black line), erroneously rejecting desirable self-attributes (solid grey line), correctly rejecting undesirable self-attributes (dashed black line), and correctly endorsing desirable self-attributes (dashed grey line), with the error-related negativity (ERN) and the positivity error (PE).

Note. msec = milliseconds and μV = microvolts.

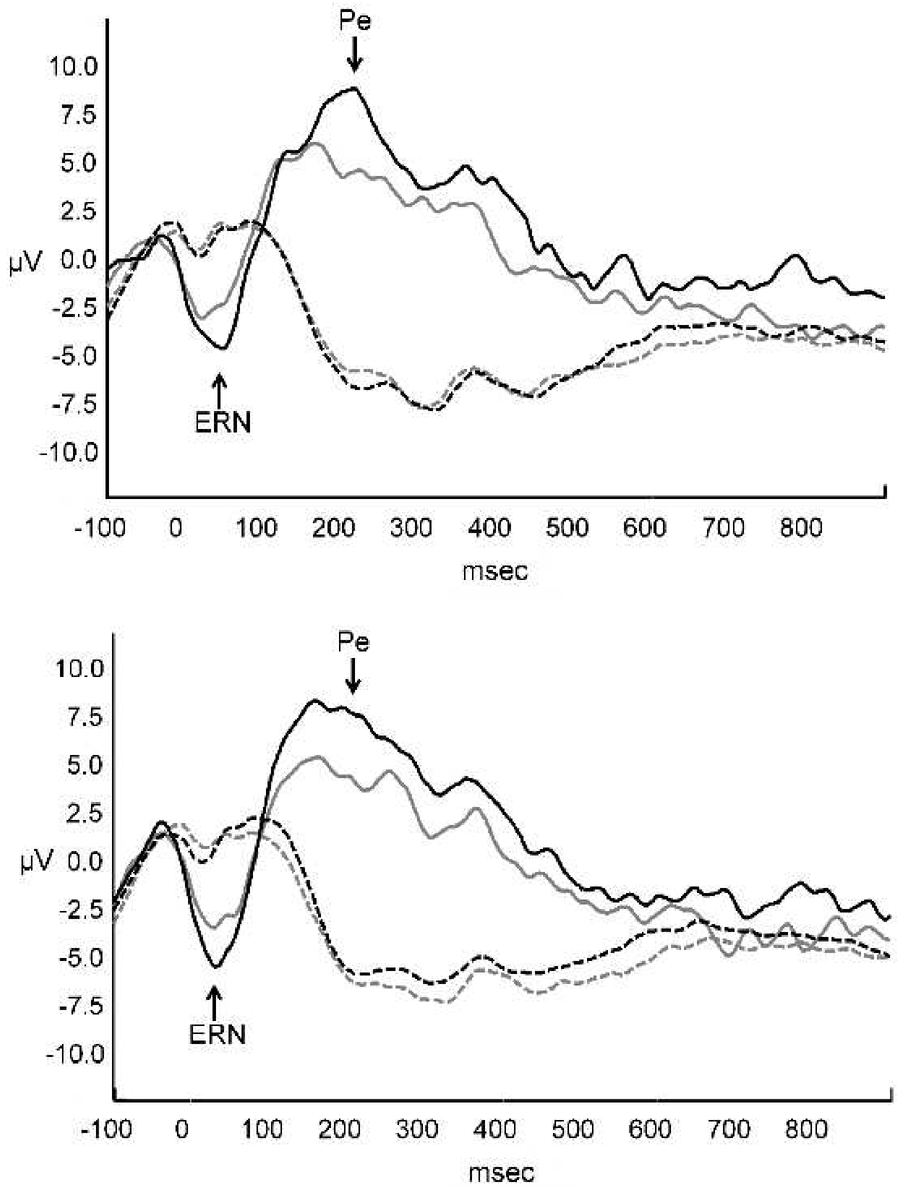


Figure 2. Event-related potentials at electrode FCZ in the first (top) and second (bottom) half of trials, response-locked to erroneously endorsing undesirable self-attributes (solid black line), erroneously rejecting desirable self-attributes (solid grey line), correctly rejecting undesirable self-attributes (dashed black line), and correctly endorsing desirable self-attributes (dashed grey line).

Note. msec = milliseconds and µV = microvolts.