Self-affirmation enhances the processing of uncertainty: An event-related potential study

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Abstract

We proposed that self-affirmation can endow people with more cognitive resource to cope with uncertainty. We tested this possibility with an event-related potential (ERP) study by examining how self-affirmation influences ambiguous feedback processing in a simple gambling task, which was used to investigate risk decision-making. We assigned 48 participants randomly to the affirmation and non-affirmation (i.e., control) groups. All participants accepted the manipulation first and then completed the gambling task with an electroencephalogram (EEG) recording, in which participants might receive a positive (winning), negative (losing), or ambiguous (unknown valence) outcome after they made a choice. We considered both the feedback-related negativity (FRN) and P3 components elicited by the outcome feedback, which reflected the amount of cognitive resources being invested in the early and late stages of the outcome feedback processing, respectively. ERP results showed that ambiguous feedback elicited a larger FRN among affirmed participants than unaffirmed participants but exerted no influence on the P3. This finding suggests that self-affirmation may help coping with uncertainty by enhancing the early processing of uncertainty.

Keywords Self-affirmation · Uncertainty · Cognitive resource · Outcome feedback · Event-related potential (ERP) · Feedback-related negativity (FRN)

Introduction

Certainty is important for human beings. A sense of certainty may make people feel secure, happy, and content (Tiedens & Linton, 2001). In reality, however, uncertainty is unavoidable. People encounter uncertainties almost every day (Hastie, 2001). For example, unexpected traffic may occur at any time, even when a particular route is familiar to a person.

Uncertainty is undesirable. Coping with uncertainty is not only a frequent daily practice, but also an important research topic. In this study, we explored whether self-affirmation, a self-regulation strategy beneficial for dealing with various stresses and threats (for a review, see Sherman & Cohen, 2006), would serve as a coping strategy for uncertainty. Specifically, we examined the influence of self-affirmation on the processing of ambiguous feedback information in a decision-making task. To do this, we conducted an event-related potential (ERP) experiment.

Ruolei Gu and Jing Yang contributed equally to this work.

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The need for certainty and dealing with uncertainty

Life is fraught with uncertainty (Hastie, 2001). Although the understanding about uncertainty varies across research areas, it is widely agreed that uncertainty is characterized by a state in which information is incomplete or conflicting (Lipshitz & Strauss, 1997). Uncertainty could refer to a condition of the world or the resulting psychological response to that condition (Platt & Huettel, 2008), and could be externally (i.e., the relevant information is unavailable) or internally (i.e., people lack the knowledge of the information) caused (Kahneman & Tversky, 1982). The processing of uncertainty may

manifest during sensory encoding, state evaluation, rule identification, and motor control (Bach & Dolan, 2012). In the human brain, uncertainty may activate various areas including the anterior cingulate cortex (encoding the level of sensory uncertainty), amygdala (indicating the surprise emotion), and parietal cortex (encoding reward probability) (Bach & Dolan, 2012; Dayan & Niv, 2008; Smith et al., 2009).

People pursue certainty and avoid ambiguity because in most cases uncertainty is intolerable (Furnham & Ribchester, 1995; Kamal & Burkell, 2013). Uncertainty may make people feel anxious and even dampen their cognitive ability further (Grupe & Nitschke, 2013; Hirsh & Inzlicht, 2008; Jonas et al., 2014; Monat, Averill, & Lazarus, 1972). When facing uncertainty, therefore, people often strive to escape from or cope with it by using diverse strategies, such as reducing, acknowledging, or suppressing uncertainty (Lipshitz & Strauss, 1997). As one of the most widely applied strategies, reducing uncertainty is particularly relevant to our current study. Typically, this strategy requires people to determine what the uncertain information actually means by learning and reasoning (Ernst & Steinhauser, 2015; Lipshitz & Strauss, 1997; Moore, Underwood, Heberlein, Doyle, & Litzie, 1979), which demands additional cognitive resources compared to the processing of certain information (Bland & Schaefer, 2012; Gibbons, Schnuerch, & Stahl, 2016). Increased cognitive resources can be inferred from enhanced capability of the frontal executive network at the neural level and heightened efficiency in finishing attention, working memory, cognitive control, and inhibition tasks at the behavioral level (Posner, Snyder, & Solso, 2004; Vecchio, 1990). They can be strengthened by diverse self-regulation strategies (Gilbert, Krull, & Pelham, 1988) but weakened by various negative conditions such as stress and fatigue (Engle, Conway, Tuholski, & Shisler, 1995; Granholm, Verney, Perivoliotis, & Miura, 2007). When cognitive resources are insufficient, the efficiency of uncertainty processing are compromised (Summerfield, Behrens, & Koechlin, 2011). Inversely put, a potential way to enhance uncertainty processing is to increase cognitive resources.

Self-affirmation and uncertainty

In this research, we proposed that self-affirmation can help people evaluate uncertain or ambiguous information by momentarily increasing their cognitive resources. Self-affirmation theory posits that people can strengthen their self-integrity by reiterating their value in one domain and thereby countering threats from other domains (Sherman & Cohen, 2006; Steele, 1988). Typically, self-affirmation manipulation entails people writing about their core personal values and then elaborating on why those values are important to them. Self-affirmation can help people cope with various stresses and life's difficulties (G. L. Cohen & Sherman, 2014; Koole, Smeets, Van Knippenberg, & Dijksterhuis,

1999; McQueen & Klein, 2006; Sherman, 2013; Sherman & Hartson, 2010). Relevant to our current study, self-affirmation can endow people with more cognitive resources in problem-solving and decision-making (DeWall, Baumeister, Mead, & Vohs, 2011; Wang, Novemsky, Dhar, & Baumeister, 2010). For instance, Cascio et al. (2016) showed that self-affirmation successfully helps participants counteract depletion of their cognitive resources caused by a heightened cognitive load. Gu et al. (2016) demonstrated that self-affirmation enables more cognitive resources during the processing of outcome in social decision-making, as reflected by greater ERP signals.

The present study

Based on the aforementioned review of previous studies, we proposed that self-affirmation may be beneficial for uncertainty processing in decision-making by providing more cognitive resources, which may manifest on the ERP associated with outcome processing. To test this hypothesis, we had participants complete a simple gambling task with electroencephalogram (EEG) recording, for each trial of which participants made a choice between two options and immediately received positive, negative, or ambiguous (uncertain) feedback (Gehring & Willoughby, 2002; Gu, Ge, Jiang, & Luo, 2010). We focused on two ERP components elicited by outcome feedback: the feedback-related negativity (FRN) and P3, which are the most important ERP indexes of outcome processing (see San Martín, 2012, for a review). The FRN peaks at approximately 200–300 ms post-onset of an event (Gehring & Willoughby, 2002; Miltner, Braun, & Coles, 1997). This fronto-central negativity is larger following erroneous/negative events than correct/positive events (Cohen, Wilmes, & van de Vijver, 2011; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004). The P3 component is a centro-parietal positivity that reaches its peak at approximately 300–600 ms (Kutas, McCarthy, & Donchin, 1977; Sutton, Braren, Zubin, & John, 1965). Although cognitive functions of the FRN and P3 are still under debate (Goyer, Woldorff, & Huettel, 2008; San Martín, 2012), researchers agree that the FRN and P3 reflect the early and late stages of outcome evaluation, respectively (Yeung & Sanfey, 2004). Specifically, while the FRN represents a quick, coarse, bottom-up detection of the value of an outcome, the P3 reflects a deliberate, comprehensive, top-down evaluation of outcome information (Philiastides, Biele, Vavatzanidis, Kazzer, & Heekeren, 2010; Wu & Zhou, 2009; Zhang et al., 2014). Both the FRN and P3 have been shown to be sensitive to the amount of cognitive resources. For instance, a smaller FRN has been observed when additional cognitive load disturbs participants' attention to outcome feedback (Krigolson,

Hassall, Satel, & Klein, 2015; Krigolson, Heinekey, Kent, & Handy, 2012). Similarly, a larger P3 component has been observed when increased cognitive resources are available (Kok, 1997; Polezzi, Sartori, Rumiati, Vidotto, & Daum, 2010; Polich, 2007; Utku, Erzen, Cakmak, & Karakas, 2002).

We conducted the current study in China. Our previous studies have demonstrated that familial self-affirmation rather than individual self-affirmation is effective for Chinese participants (Cai, Sedikides, & Jiang, 2013; Gu et al., 2016). Hence, we asked half of the participants to affirm their familial self by choosing a value that is important for both themselves as well as for their family, and explain why that value is important (affirmation group). For the remaining half of the participants, we instructed them to select their least important value for both themselves and their family, and similarly explain why that value is unimportant to them (control group). Following the self-affirmation or control manipulation, we had all participants complete a simple gambling task, during which we recorded the ERP signals elicited by outcome presentation. We expected that self-affirmation would mobilize more cognitive resources to process feedback as indicated by an enlarged FRN or P3, or both. More specifically, we expected that when facing ambiguous feedback that requires additional cognitive resources, the effect of increased cognitive resources would manifest on at least one of two ERP indexes; when the feedback was certain and feedback processing entailed only minimum cognitive resources, however, increase cognitive resources might or might not make a difference on the ERPs.

Methods

Participants

We recruited 50 Chinese college students online to participate in the experiment. They were from universities located near the Institute of Psychology Chinese Academy of Sciences, such as Beijing Forestry University and China Agricultural University. We determined the sample size based on two considerations: (1) How many participants were usually involved in previous between-group ERP studies (e.g., Li et al., 2015; Pintzinger, Pfabigan, Pfau, Kryspin-Exner, & Lamm, 2017; Webb et al., 2017), and (2) how many participants are needed to ensure 80% statistical power to detect a small-to-medium effect size (Vazire, 2016). Accordingly, we invited 50 college students to participate in the experiment. Two students declined our invitation, which resulted in a final sample of 48 participants.

We randomly assigned half of the students to the familial self-affirmation group (twenty females) and the other half to

the control group (nine females). An independent-samples *t* test revealed that the participants in the two groups did not differ in age (affirmation condition: 23.46 ± 2.13 [mean $\pm$ standard deviation, hereinafter the same] years, control condition: 24.29 ± 2.60 years; $t(46) = 1.22$, $p = .230$).

All participants were free of regular use of any substance that might influence the central nervous system. All participants denied a history of neurological and psychiatric disorders. In addition, all had normal vision (with correction) and were right-handed according to their self-report. Everyone provided written informed consent prior to the experiment. The Institutional Review Board (IRB) in the Institute of Psychology Chinese Academy of Sciences approved the experimental protocol.

Procedure

The self-affirmation procedure was derived from Cai et al. (2013). In the self-affirmation group, participants were required to choose one value that they and their family cherished most from among four domains, including financial wealth, social network, art/creativity, and knowledge. Then they were asked to record the reason why their chosen value was important to them and their family (no less than 150 words). Finally, we required the participants to describe an experience in which they realized how important this value was to them and their family (no less than 150 words). In the control group, participants chose a value that was least important to themselves and their family, recorded why this value was least important, and described an experience via which they realized that this value was least important. Doing this could make participants direct attention away from themselves, thus forming a better contrast to the experimental condition in which self was the focus.

After the affirmation manipulation, participants in both groups were instructed on the rules of a two-option forced-choice gambling task (see Fig. 1), which reliably elicits the ERP components FRN and P3 (San Martín, 2012; Yeung & Sanfey, 2004). We informed participants of the meaning of symbols in the task. They were encouraged to respond in a way that would maximize the total score, which would then determine their bonus money at the end of the experiment. All participants acquired familiarity with the task through 12 practice trials.

Stimulus display and behavioral data acquisition were conducted using E-Prime software (Version 2.0, Psychology Software Tools, Inc., Sharpsburg, PA, USA). During the task, participants sat comfortably in an electrically-shielded room approximately 80 cm from a 17-in. CRT computer monitor (refresh rate: 85 Hz; resolution: $1,024 \times 768$ pixels). Each trial began with the presentation of a central fixation point (white against a black background). After 1,200 ms, two white rectangles ($2.5^\circ \times 2.5^\circ$) appeared on either side of the fixation

Fig. 1 (a) The self-affirmation manipulation stage, which was administered with paper and pen. (b) An example trial in the gambling task stage, which was administered via a computer. *RT* response time

point, in either of which the number “9” or “99” was individually presented. According to classical decision-making theories (e.g., Fox, Erner, & Walters, 2016), the option “9” represents a low-risk and low-return option, whereas the option “99” represents a high-risk and high-return option. The positions of these two options were counterbalanced across trials. Participants had 4,000 ms to make a decision between two options by pressing the “F” or “J” keys on the keyboard with their left or right index finger, respectively. The selected option was highlighted by a thick red outline for 500 ms. Then the numbers disappeared for a short interval of random duration between 800 and 1,200 ms. Finally, the valence of outcome feedback was presented in the chosen rectangle for 1,000 ms. The formal task consisted of three blocks of 160 trials each. Participants rested during the interval of two blocks for approximately 3 min.

There were three kinds of possible feedback valence: “+”, “−”, and “*”. The “+” symbol (positive feedback) indicated that participants accrued as many points as they chose in this trial, while the “−” symbol (negative feedback) indicated the reverse. The “*” symbol denoted ambiguous (uninformative) feedback, of which the actual valence might be positive or negative. One of our previous studies has shown that ambiguous feedback elicits different subjective experiences compared to neutral feedback (i.e., zero; see Gu, Ge, et al., 2010). Unbeknown to participants, outcome feedback was provided according to a pre-determined pseudorandom sequence, and all participants received exactly 160 outcomes of each type of valence. At the end of the task, participants were informed of the total score that they had earned, and then were paid 60–80 Chinese yuan for their participation.

Electrophysiological recording and preprocessing

The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc.) with an online reference to the left mastoid and off-line algebraic re-reference to the average of the left and right mastoids. An electro-oculogram (EOG) was recorded for the purpose of artifact correction. Horizontal EOG (HEOG) was recorded from electrodes placed at the outer canthi of both eyes. Vertical EOG (VEOG) was recorded from electrodes placed above and below the left eye. All inter-

electrode impedance was maintained at < 5 kΩ. EEG and EOG signals were amplified with a 0.05–100 Hz online band-pass filter and continuously sampled at 500 Hz/channel.

During the offline analysis, we removed the ocular artifacts from the EEG signal using a regression procedure implemented with Neuroscan software (Semlitsch, Anderer, Schuster & Presslich, 1986). After 0.05–30 Hz band-pass digital filtering through a zero phase shift, the EEG data were segmented into epochs time-locked to the onset of outcome feedback. Separate EEG epochs of 1,000 ms were baseline-corrected by subtracting from each sample the average activity of that channel during the −200- to 0-ms baseline period. Finally, any trial in which EEG voltages exceeded a threshold of $\pm 100 \mu\text{V}$ during the recording epoch was excluded from further analysis.

After the data preprocessing described above, the trials that survived were determined as being artifact-free (“+9”: 76.94 ± 29.40 trials; “+99”: 76.10 ± 28.42 trials; “−9”: 75.60 ± 28.08 trials; “−99”: 75.44 ± 28.18 trials; “*9”: 72.08 ± 27.74 trials; “*99”: 73.96 ± 26.75 trials). According to the literature, the remaining trials were enough to obtain a reliable FRN as well as P3 with a high signal-to-noise ratio (J. Cohen & Polich, 1997; Marco-Pallares, Cucurell, Munte, Strien, & Rodriguez-Fornells, 2011).

Data analysis

Basically, there are two ways to calculate the FRN amplitude: using the grand-averaged waveforms, or creating a difference wave between winning and losing trials (Holroyd & Krigolson, 2007; Wu & Zhou, 2009). We chose the latter one for two reasons. First, the difference wave approach can remove common underlying components that are insensitive to the win/loss manipulation (Bress, Smith, Foti, Klein, & Hajcak, 2012) and at the same time minimize potential overlaps between the FRN and other ERP components, particularly the P3 (Hajcak, Moser, Holroyd, & Simons, 2007; Holroyd & Krigolson, 2007). Second, we have successfully used the difference approach in relevant studies (e.g., Gu et al., 2016; Zhu, Gu, Wu, & Luo, 2015; Zhu et al., 2018). Thus, we created “negative-positive” and “ambiguous-positive” difference waves by subtracting the ERPs on positive outcome trials from the ERPs on negative and ambiguous outcome trials, respectively.

The FRN has been reported to be maximal in the fronto-central area of the scalp (Holroyd & Krigolson, 2007; Oliveira, McDonald, & Goodman, 2007), whereas the P3 associated with feedback processing appears to be maximal in the centro-parietal area (Lust & Bartholow, 2009; Nieuwenhuis, Aston-Jones, & Cohen, 2005). In this study, the FRN amplitude was calculated as the mean value within the 220- to 320-ms window following the outcome feedback presentation across three midline electrodes (Fz, FCz, Cz) in the frontocentral-central region. The P3 amplitude was similarly calculated within the 300- to 450-ms window across three midline electrodes (Cz, CPz, Pz) in the centro-parietal region (see also Gu, Wu, Jiang, & Luo, 2011). Since collapsing the data across electrode sites helps simplify the statistical models and increase the signal-to-noise ratio (Luck & Gaspelin, 2017), the arithmetical means of these electrodes were calculated. The time windows were selected through visual inspection of grand-averaged waveforms (see Figs. 2 and 3).

Regarding the statistical analyses on the FRN and P3 amplitudes, two within-subject factors (i.e., outcome valence and magnitude) and one between-subject factor (i.e., self-affirmation manipulation) were taken into account. For all analyses, the significance level was set at .05. Greenhouse–Geisser corrections were applied when appropriate. Significant interactions were analyzed using simple-effects models. Partial eta squared (η_p^2) values were reported to examine the size of effects in the models of analysis of variance (ANOVA), where .05 represented a

small effect, .1 represented a medium effect, and .2 represented a large effect (J. Cohen, 1973). Only significant results were reported for the sake of brevity.

Results

Behavioral results

Participants in the affirmation group did not significantly differ from those in the control group in either the ratio of making high-risk choices ($49.07 \pm 17.55\%$ vs. $49.96 \pm 16.82\%$, $t(46) = 0.18$, $p = .859$) or the reaction time (affirmation group: 581.02 ± 128.58 ms, control group: 649.65 ± 265.67 ms, $t(46) = 1.14$, $p = .261$). These results suggested that affirmation did not influence behavioral performance. See [Online Supplementary Material](#) (Part A) for further analysis on behavioral data.

ERP results

FRN amplitude A three-way Self-affirmation (affirmation vs. control) $\times$ Outcome Valence (negative-positive vs. ambiguous-positive) $\times$ Outcome Magnitude (small vs. large) ANOVA test revealed a significant main effect of Valence ($F(1, 46) = 24.96$, $p < .001$, $\eta_p^2 = .35$); the FRN was larger following ambiguous feedback (-2.03 ± 1.19 μV) than after negative feedback (-1.39 ± 1.24 μV) (see also Gu, Huang, & Luo, 2010). Here, a smaller amplitude value denotes a larger FRN because the FRN is a negative-

Fig. 2 (a) Grand-average event-related potentials (ERPs) elicited by outcome feedback at the Fz recording site, where the FRN difference wave reached its maximum. (b) Difference waves created by subtracting the ERPs in the positive condition from those in the negative condition and ambiguous condition, respectively. The time

point “0” indicates outcome presentation onset. The gray-shaded areas indicate the 220- to 320-ms time window for the calculation of the mean value of the FRN difference wave. The electrodes used in data analysis on the FRN were Fz, FCz, and Cz

going component. The main effect of Magnitude was also significant ($F(1, 46) = 8.45, p = .006, \eta_p^2 = .16$); the FRN was larger in response to large feedback ($-1.99 \pm 1.28 \mu\text{V}$) compared with small feedback ($-1.43 \pm 1.34 \mu\text{V}$). The main effect of Self-affirmation was not significant ($F(1, 46) = 1.14, p = .292, \eta_p^2 = .024$).

Most interestingly, the Self-affirmation $\times$ Valence interaction was significant ($F(1, 46) = 8.56, p = .005, \eta_p^2 = .16$); the FRN following ambiguous feedback was larger than that following negative feedback ($-2.37 \pm 1.20 \mu\text{V}$ vs. $-1.37 \pm 1.30 \mu\text{V}$; $p < .001$) in the affirmation group, but this was not the case in the control group ($-1.68 \pm 1.14 \mu\text{V}$ vs. $-1.41 \pm 1.19 \mu\text{V}$; $p = .150$). Alternatively, the FRN was larger in the affirmation group than in the control group following ambiguous feedback ($p = .030$), while there was no between-group difference following negative feedback ($p = .903$) (see Fig. 2).

The Self-affirmation $\times$ Magnitude interaction was not significant ($F(1, 46) = 2.89, p = .096, \eta_p^2 = .06$). The Valence $\times$ Magnitude interaction was significant ($F(1, 46) = 5.20, p = .027, \eta_p^2 = .10$); the difference between negative and ambiguous feedback was much larger in the small magnitude condition ($-0.98 \pm \mu\text{V}$ vs. $-1.81 \pm \mu\text{V}$; $p < .001$) compared to the large magnitude condition ($-1.87 \pm \mu\text{V}$ vs. $-2.18 \pm \mu\text{V}$; $p = .035$). Finally, the Self-affirmation $\times$ Valence $\times$ Magnitude interaction was not significant ($F(1, 46) = 0.80, p = .377, \eta_p^2 = .02$).

P3 amplitude A three-way Self-affirmation (affirmation vs. control) $\times$ Outcome Valence (positive vs. negative vs. ambiguous) $\times$ Outcome Magnitude (small vs. large) ANOVA test was conducted (see Fig. 3). The main effect of Valence was significant ($F(2, 92) = 8.43, p = 0.001, \eta_p^2 = .16$); the

P3 was larger in response to positive feedback ($14.21 \pm 5.42 \mu\text{V}$) than in response to negative feedback ($12.45 \pm 5.28 \mu\text{V}$; $p < .001$) or ambiguous feedback ($12.93 \pm 5.84 \mu\text{V}$; $p = .013$), while negative and ambiguous feedback made no significant difference ($p = .300$). The main effect of Magnitude was also significant ($F(1, 46) = 123.41, p < .001, \eta_p^2 = .73$); the P3 was larger in response to large feedback ($15.79 \pm 6.22 \mu\text{V}$) than to small feedback ($10.61 \pm 4.67 \mu\text{V}$). The main effect of Self-affirmation was not significant ($F(1, 46) = 0.83, p = .366, \eta_p^2 = .02$).

Neither the Self-affirmation $\times$ Valence interaction ($F(1, 46) = 0.28, p = .733, \eta_p^2 = .01$), nor the Self-affirmation $\times$ Magnitude interaction ($F(1, 46) < 0.01, p = .976, \eta_p^2 < .01$), nor the Valence $\times$ Magnitude interaction ($F(1, 46) = 0.87, p = .407, \eta_p^2 = .02$), nor the Self-affirmation $\times$ Valence $\times$ Magnitude interaction ($F(1, 46) = 1.04, p = .348, \eta_p^2 = .02$) was significant.

Finally, regarding the latencies of the FRN and P3, please see [Online Supplementary Material](#) (Part C).

Discussion

Uncertainty is intolerable. In this paper, we proposed that self-affirmation can help people cope with uncertainty by retrieving more cognitive resources. To test this possibility, we employed a risk decision-making task involving both uncertain or ambiguous outcome feedback, and used two ERP components, including the FRN and P3, to reflect the cognitive resources allocated to the early and late stages of outcome processing, respectively. We did not find any significant

Fig. 3 Grand-average event-related potentials (ERPs) elicited by outcome feedback at the CPz recording site, where the P3 component reached its maximum. The time point “0” indicates outcome presentation

onset. The gray-shaded areas indicate the 300- to 450-ms time window for the calculation of the mean value of the P3 amplitude. The electrodes used in data analysis on the P3 were Cz, CPz, and Pz

influence of self-affirmation on behavioral response, which is not rare when the feedback probability was controlled (Gu, Ge, et al., 2010; Gu, Huang, et al., 2010). However, we replicated the main findings of past ERP studies on decision-making: first, the FRN showed similar amplitude in response to ambiguous and negative feedback in the control group (Becker, Nitsch, Miltner, & Straube, 2014; Gu et al., 2017; Holroyd, Hajcak, & Larsen, 2006); second, the P3 is larger in response to large magnitude feedback over small and to positive feedback compared to negative and ambiguous feedback (Gu, Ge, et al., 2010; Gu, Lei, et al., 2011). These findings suggest that using the gambling task with EEG recording was successful. Importantly, we obtained supportive evidence for our hypothesis: self-affirmation exerted pronounced influence on the FRN when the feedback was ambiguous, though its effect in other conditions was not significant. These findings suggest that self-affirmation can mobilize more cognitive resources at the early stage of uncertain feedback processing.

Legault, Al-Khindi, and Inzlicht (2012) conducted the first ERP study on self-affirmation by examining how self-affirmation affects the ERPs in response to incorrect reactions during a Go–No-go task. They found that self-affirmation enlarged the error-related negativity (ERN) peaking at approximately 100 ms, which further explains the resultant improvement in behavioral performance. The ERN is a response-locked ERP component elicited by erroneous behavioral responses. The ERN and FRN are similar in morphology, scalp topography, and latency (Nieuwenhuis et al., 2004), and therefore are considered as manifestations of the same cognitive and neural processes (for reviews, see Holroyd & Coles, 2002; Simons, 2010). In line with the ERN finding from Legault et al. (2012), the current study found that self-affirmation affects the early stage of feedback processing. Inconsistent with Legault et al., however, we found that self-affirmation makes a difference in the ambiguous but not negative condition. Following a prevailing explanation in behavioral studies (e.g., Cai et al., 2013), Legault et al. suggested that the enlarged ERN reflects the utility of self-affirmation in promoting openness to an unfavorable outcome. This account of openness, however, might not be applicable in our case. Otherwise, we should have also observed an enlarged FRN among those affirmed participants when negative feedback was given in our study. In one of our previous studies (Gu et al., 2016), we proposed that increased cognitive resources explain the effect of self-affirmation on the processing of unfair offers in a social decision-making situation. That is, self-affirmation endows more cognitive resources in evaluating an unfavorable outcome, which manifests on the ERPs elicited by outcome feedback. With this account, findings in both the study of Legault et al. (2012) and our study can be explained parsimoniously. That is, both the enlarged ERN

and FRN reflect increased availability of cognitive resources enabled by self-affirmation manipulation.

The above interpretations assume that performance monitoring and processing error response in a Go–No-go task and ambiguous feedback in a gambling task demand more cognitive resources compared with externally provided negative feedback. This is possible given the following facts. First, compared with monitoring external feedback valence in gambling, monitoring the internal error response in a Go–No-go task requires participants to assess whether the response is correct or not, which should demand additional cognitive resources. Second, ambiguous feedback is not only aversive, making it similar to negative feedback (Holroyd et al., 2006), but also uncertain, thus demanding more cognitive resources to be processed (Bland & Schaefer, 2012; Gibbons et al., 2016). In summary, the cognitive resources account provides a reasonable interpretation for our findings. It, however, does not suggest that the openness account is wrong. Instead, it is possible that what underlies increased openness is increased cognitive resources.

The current findings deepen the understanding of the nature of ambiguous feedback and negative feedback by pinpointing both the similarity and dissimilarity between them. Previous studies have shown that the FRN elicited by ambiguous feedback is similar to that elicited by negative feedback (Hajcak, Moser, Holroyd, & Simons, 2006), suggesting that they both are negative in nature. We replicated this finding by showing that ambiguous and negative feedback made no difference in the FRN among unaffirmed participants. Of most interest, we show that ambiguous feedback elicited a significantly larger FRN than negative feedback among affirmed participants. These findings suggest that although both kinds of feedback are negative, ambiguous feedback entails more cognitive resources to be effectively processed.

Nevertheless, one might suggest that our findings can also be interpreted according to the classic “prediction error” account of the FRN (Hajcak et al., 2007; Oliveira et al., 2007). This account assumes that self-affirmation may heighten the expectation of a certain and positive outcome and, consequently, exaggerate the violation aversion caused by uncertain (ambiguous) or negative feedback. In this case, FRN serves as an indicator of prediction error or violation aversion. We disagree with this interpretation for our FRN results for two reasons. First, this interpretation contradicts the account that self-affirmation can enhance positive feelings and openness (rather than aversion) in response to negative feedback (Legault et al., 2012; Sherman & Cohen, 2006). Second, this interpretation could not explain why ambiguous feedback elicited a larger FRN than did a negative one.

One might also suggest that an enlarged FRN reflects an enhanced capability of performance monitoring rather than cognitive resources given the established association between

the FRN and performance monitoring (Gentsch, Grandjean, & Scherer, 2013; Oliveira et al., 2007; Pfabigan et al., 2015). We agree with this possibility, but do not think that the performance monitoring and cognitive resource accounts conflict with each other. Actually, increased cognitive resources might provide an explanation for the enhanced capability of performance monitoring because performance monitoring consumes cognitive resources (e.g., Johns, Inzlicht, & Schmader, 2008). That is, self-affirmation provides participants with more cognitive resources, which may further heighten the capability of performance monitoring.

Some researchers may have expected that self-affirmation produces a significant influence on both the FRN and the P3. We found, however, that self-affirmation selectively affects the FRN but not the P3. In a similar prior study (Gu et al., 2016), we examined how self-affirmation influences the FRN and P3 elicited by unfair feedback in a social decision-making task, and found that self-affirmation selectively influences the P3 but not the FRN. In both studies, we assumed that the FRN and P3 are indexes of cognitive resources that participants invest in outcome processing. From our perspective, findings from these two studies suggest that self-affirmation can increase the availability of cognitive resources momentarily on the one hand; on the other hand, the specific stage (early or late) of outcome processing modulated by self-affirmation may vary with task features (e.g., social or non-social decision-making) and situations (e.g., involving others or not). More studies with a sophisticated design, however, are needed to understand this possibility.

In brief, we gathered preliminary evidence for the use of self-affirmation in facilitating uncertainty processing. Nevertheless, our study is limited in several ways. First, we only examined one kind of uncertainty situation, that is, ambiguous feedback in a gambling task. Uncertainty manifests in many situations and tasks (Bach & Dolan, 2012). Future studies may examine, for example, whether self-affirmation would also modulate uncertainty processing during social decision-making. Second, self-affirmation can be operationalized in diverse ways (McQueen & Klein, 2006; Sherman & Cohen, 2006), but we have only examined a single paradigm of self-affirmation, that is, value affirmation. Follow-up studies with other affirmation paradigms are needed. Third, compared with behavioral studies, the sample we used is relatively small. Future replications may use larger samples.

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Authors contributions RG and HC conceived and designed the experiments. JY performed the experiments. RG and JY analyzed the data. RG, ZY, ZH, and HC wrote and revised the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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References

- Bach, D. R., & Dolan, R. J. (2012). Knowing how much you don't know: A neural organization of uncertainty estimates. *Nature Reviews Neuroscience*, 13(8), 572–586. doi:<https://doi.org/10.1038/nrn3289>
- Becker, M. P., Nitsch, A. M., Miltner, W. H., & Straube, T. (2014). A single-trial estimation of the feedback-related negativity and its relation to BOLD responses in a time-estimation task. *Journal of Neuroscience*, 34(8), 3005–3012. doi:<https://doi.org/10.1523/JNEUROSCI.3684-13.2014>
- Bland, A. R., & Schaefer, A. (2012). Different varieties of uncertainty in human decision-making. *Frontiers in Neuroscience*, 6, 85. doi:<https://doi.org/10.3389/fnins.2012.00085>
- Bress, J. N., Smith, E., Foti, D., Klein, D. N., & Hajcak, G. (2012). Neural response to reward and depressive symptoms in late childhood to early adolescence. *Biological Psychology*, 89(1), 156–162. doi:<https://doi.org/10.1016/j.biopsycho.2011.10.004>
- Cai, H., Sedikides, C., & Jiang, L. (2013). Familial self as a potent source of affirmation: Evidence from China. *Social Psychological and Personality Science*, 4(5), 529–537. doi:<https://doi.org/10.1177/1948550612469039>
- Cascio, C. N., O'Donnell, M. B., Tinney, F. J., Lieberman, M. D., Taylor, S. E., Strecher, V. J., & Falk, E. B. (2016). Self-affirmation activates brain systems associated with self-related processing and reward and is reinforced by future orientation. *Social Cognitive and Affective Neuroscience*, 11(4), 621–629. doi:<https://doi.org/10.1093/scan/nsv136>
- Cohen, G. L., & Sherman, D. K. (2014). The psychology of change: Self-affirmation and social psychological intervention. *Annual Review of Psychology*, 65, 333–371. doi:<https://doi.org/10.1146/annurev-psych-010213-115137>
- Cohen, J. (1973). Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educational and Psychological Measurement*, 33(1), 107–112. doi:<https://doi.org/10.1177/001316447303300111>
- Cohen, J., & Polich, J. (1997). On the number of trials needed for P300. *International Journal of Psychophysiology*, 25(3), 249–255. doi:[https://doi.org/10.1016/S0167-8760\(96\)00743-X](https://doi.org/10.1016/S0167-8760(96)00743-X)
- Cohen, M. X., Wilmes, K., & van de Vijver, I. (2011). Cortical electrophysiological network dynamics of feedback learning. *Trends in Cognitive Sciences*, 15(12), 558–566. doi:<https://doi.org/10.1016/j.tics.2011.10.004>
- Dayan, P., & Niv, Y. (2008). Reinforcement learning: The good, the bad and the ugly. *Current Opinion in Neurobiology*, 18(2), 185–196. doi:<https://doi.org/10.1016/j.conb.2008.08.003>
- DeWall, C. N., Baumeister, R. F., Mead, N. L., & Vohs, K. D. (2011). How leaders self-regulate their task performance: Evidence that power promotes diligence, depletion, and disdain. *Journal of Personality and Social Psychology*, 100(1), 47–65. doi:<https://doi.org/10.1037/a0020932>
- Engle, R. W., Conway, A. R., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science*, 6(2), 122–125. doi:<https://doi.org/10.1111/j.1467-9280.1995.tb00318.x>
- Ernst, B., & Steinhauser, M. (2015). Effects of invalid feedback on learning and feedback-related brain activity in decision-making. *Brain*

- and Cognition, 99, 78–86. doi:<https://doi.org/10.1016/j.bandc.2015.07.006>
- Fox, C. R., Emer, C., & Walters, D. J. (2016). Decision Under risk: From the field to the laboratory and back. In G. Keren & G. Wu (Eds.), *The Wiley Blackwell handbook of judgment and decision making* (Vol. 1, pp. 43–88). West Sussex, UK: John Wiley & Sons.
- Furnham, A., & Ribchester, T. (1995). Tolerance of ambiguity: A review of the concept, its measurement and applications. *Current Psychology*, 14(3), 179–199. doi:<https://doi.org/10.1007/BF02686907>
- Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, 295(5563), 2279–2282. doi:<https://doi.org/10.1126/science.1066893>
- Gentsch, K., Grandjean, D., & Scherer, K. R. (2013). Temporal dynamics of event-related potentials related to goal conduciveness and power appraisals. *Psychophysiology*, 50(10), 1010–1022. doi:<https://doi.org/10.1111/psyp.12079>
- Gibbons, H., Schnuerch, R., & Stahl, J. (2016). From positivity to negativity bias: Ambiguity affects the neurophysiological signatures of feedback processing. *Journal of Cognitive Neuroscience*, 28(4), 542–557. doi:https://doi.org/10.1162/jocn_a_00921
- Gilbert, D. T., Krull, D. S., & Pelham, B. W. (1988). Of thoughts unspoken: Social inference and the self-regulation of behavior. *Journal of Personality and Social Psychology*, 55(5), 685–694. doi:<https://doi.org/10.1037/0022-3514.55.5.685>
- Goyer, J. P., Woldorff, M. G., & Huettel, S. A. (2008). Rapid electrophysiological brain responses are influenced by both valence and magnitude of monetary rewards. *Journal of Cognitive Neuroscience*, 20(11), 2058–2069. doi:<https://doi.org/10.1162/jocn.2008.20134>
- Granholm, E., Verney, S. P., Perivoliotis, D., & Miura, T. (2007). Effortful cognitive resource allocation and negative symptom severity in chronic schizophrenia. *Schizophrenia Bulletin*, 33(3), 831–842. doi:<https://doi.org/10.1093/schbul/sbl040>
- Grupe, D. W., & Nitschke, J. B. (2013). Uncertainty and anticipation in anxiety: An integrated neurobiological and psychological perspective. *Nature Reviews Neuroscience*, 14(7), 488–501. doi:<https://doi.org/10.1038/nrn3524>
- Gu, R., Feng, X., Broster, L. S., Yuan, L., Xu, P., & Luo, Y.-j. (2017). Valence and magnitude ambiguity in feedback processing. *Brain and Behavior*, 7(7), e00672. doi:<https://doi.org/10.1002/brb3.672>
- Gu, R., Ge, Y., Jiang, Y., & Luo, Y. J. (2010). Anxiety and outcome evaluation: The good, the bad and the ambiguous. *Biological Psychology*, 85(2), 200–206. doi:<https://doi.org/10.1016/j.biopsycho.2010.07.001>
- Gu, R., Huang, Y. X., & Luo, Y. J. (2010). Anxiety and feedback negativity. *Psychophysiology*, 47(5), 961–967. doi:<https://doi.org/10.1111/j.1469-8986.2010.00997.x>
- Gu, R., Lei, Z., Broster, L., Wu, T., Jiang, Y., & Luo, Y. J. (2011). Beyond valence and magnitude: A flexible evaluative coding system in the brain. *Neuropsychologia*, 49(14), 3891–3897. doi:<https://doi.org/10.1016/j.neuropsychologia.2011.10.006>
- Gu, R., Wu, T., Jiang, Y., & Luo, Y. J. (2011). Woulda, coulda, shoulda: The evaluation and the impact of the alternative outcome. *Psychophysiology*, 48(10), 1354–1360. doi:<https://doi.org/10.1111/j.1469-8986.2011.01215.x>
- Gu, R., Yang, J., Shi, Y., Luo, Y., Luo, Y. L. L., & Cai, H. (2016). Be strong enough to say no: Self-affirmation increases rejection to unfair offers. *Frontiers in Psychology*, 7, 1824. doi:<https://doi.org/10.3389/fpsyg.2016.01824>
- Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological Psychology*, 71(2), 148–154. doi:<https://doi.org/10.1016/j.biopsycho.2005.04.001>
- Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2007). It's worse than you thought: The feedback negativity and violations of reward prediction in gambling tasks. *Psychophysiology*, 44(6), 905–912. doi:<https://doi.org/10.1111/j.1469-8986.2007.00567.x>
- Hastie, R. (2001). Problems for judgment and decision making. *Annual Review of Psychology*, 52, 653–683. doi:<https://doi.org/10.1146/annurev.psych.52.1.653>
- Hirsh, J. B., & Inzlicht, M. (2008). The devil you know: Neuroticism predicts neural response to uncertainty. *Psychological Science*, 19(10), 962–967. doi:<https://doi.org/10.1111/j.1467-9280.2008.02183.x>
- 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(4), 679–709. doi:<https://doi.org/10.1037/0033-295X.109.4.679>
- Holroyd, C. B., Hajcak, G., & Larsen, J. T. (2006). The good, the bad and the neutral: Electrophysiological responses to feedback stimuli. *Brain Research*, 1105(1), 93–101. doi:<https://doi.org/10.1016/j.brainres.2005.12.015>
- Holroyd, C. B., & Krigolson, O. E. (2007). Reward prediction error signals associated with a modified time estimation task. *Psychophysiology*, 44(6), 913–917. doi:<https://doi.org/10.1111/j.1469-8986.2007.00561.x>
- Johns, M., Inzlicht, M., & Schmader, T. (2008). Stereotype threat and executive resource depletion: Examining the influence of emotion regulation. *Journal of Experimental Psychology: General*, 137(4), 691–705. doi:<https://doi.org/10.1037/a0013834>
- Jonas, E., McGregor, I., Klackl, J., Agroskin, D., Fritsche, I., Holbrook, C., ... Quirin, M. (2014). Threat and defense: From anxiety to approach. In J. M. Olson & M. P. Zanna (Eds.), *Advances in Experimental Social Psychology* (Vol. 49, pp. 219–286). San Diego, CA: Academic Press.
- Kahneman, D., & Tversky, A. (1982). Variants of uncertainty. *Cognition*, 11(2), 143–157. doi:[https://doi.org/10.1016/0010-0277\(82\)90023-3](https://doi.org/10.1016/0010-0277(82)90023-3)
- Kamal, A. M., & Burkell, J. (2013). Uncertainty revisited: People and information in a world of unknowns. *Canadian Journal of Information and Library Science*, 35(4), 384–396. doi:<https://doi.org/10.1353/ils.2011.0030>
- Kok, A. (1997). Event-related-potential (ERP) reflections of mental resources: A review and synthesis. *Biological Psychology*, 45(1–3), 19–56. doi:[https://doi.org/10.1016/S0301-0511\(96\)05221-0](https://doi.org/10.1016/S0301-0511(96)05221-0)
- Koole, S. L., Smeets, K., Van Knippenberg, A., & Dijksterhuis, A. (1999). The cessation of rumination through self-affirmation. *Journal of Personality and Social Psychology*, 77(1), 111–125. doi:<https://doi.org/10.1037/0022-3514.77.1.111>
- Krigolson, O. E., Hassall, C. D., Satel, J., & Klein, R. M. (2015). The impact of cognitive load on reward evaluation. *Brain Research*, 1627, 225–232. doi:<https://doi.org/10.1016/j.brainres.2015.09.028>
- Krigolson, O. E., Heinekey, H., Kent, C. M., & Handy, T. C. (2012). Cognitive load impacts error evaluation within medial-frontal cortex. *Brain Research*, 1430, 62–67. doi:<https://doi.org/10.1016/j.brainres.2011.10.028>
- Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science*, 197(4305), 792–795. doi:<https://doi.org/10.1126/science.887923>
- Legault, L., Al-Khindi, T., & Inzlicht, M. (2012). Preserving integrity in the face of performance threat: Self-affirmation enhances neurophysiological responsiveness to errors. *Psychological Science*, 23(12), 1455–1460. doi:<https://doi.org/10.1177/0956797612448483>
- Li, P., Song, X., Wang, J., Zhou, X., Li, J., Lin, F., ... Roberson, D. (2015). Reduced sensitivity to neutral feedback versus negative feedback in subjects with mild depression: Evidence from event-related potentials study. *Brain and Cognition*, 100, 15–20. doi:<https://doi.org/10.1016/j.bandc.2015.08.004>
- Lipshitz, R., & Strauss, O. (1997). Coping with uncertainty: A naturalistic decision-making analysis. *Organizational Behavior and Human*

- Decision Processes*, 69(2), 149–163. doi:<https://doi.org/10.1006/obhd.1997.2679>
- Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, 54(1), 146–157. doi:<https://doi.org/10.1111/psyp.12639>
- Lust, S. A., & Bartholow, B. D. (2009). Self-reported and P3 event-related potential evaluations of condoms: Does what we say match how we feel? *Psychophysiology*, 46(2), 420–424. doi:<https://doi.org/10.1111/j.1469-8986.2008.00775.x>
- Marco-Pallares, J., Cucurell, D., Munte, T. F., Strien, N., & Rodriguez-Fornells, A. (2011). On the number of trials needed for a stable feedback-related negativity. *Psychophysiology*, 48(6), 852–860. doi:<https://doi.org/10.1111/j.1469-8986.2010.01152.x>
- McQueen, A., & Klein, W. M. (2006). Experimental manipulations of self-affirmation: A systematic review. *Self and Identity*, 5(4), 289–354. doi:<https://doi.org/10.1080/15298860600805325>
- 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(6), 788–798. doi:<https://doi.org/10.1162/jocn.1997.9.6.788>
- 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(2), 237–253. doi:<https://doi.org/10.1037/h0033297>
- Moore, B., Underwood, B., Heberlein, P., Doyle, L., & Litzie, K. (1979). Generalization of feedback about performance. *Cognitive Therapy and Research*, 3(4), 371–380. doi:<https://doi.org/10.1007/BF01184452>
- Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin*, 131(4), 510–532. doi:<https://doi.org/10.1037/0033-2909.131.4.510>
- Nieuwenhuis, S., Yeung, N., Holroyd, C. B., Schurger, A., & Cohen, J. D. (2004). Sensitivity of electrophysiological activity from medial frontal cortex to utilitarian and performance feedback. *Cerebral Cortex*, 14(7), 741–747. doi:<https://doi.org/10.1093/cercor/bbh034>
- Oliveira, F. T. P., McDonald, J. J., & Goodman, D. (2007). Performance monitoring in the anterior cingulate is not all error related: Expectancy deviation and the representation of action-outcome associations. *Journal of Cognitive Neuroscience*, 19(12), 1994–2004. doi:<https://doi.org/10.1162/jocn.2007.19.12.1994>
- Pfabigan, D. M., Seidel, E. M., Paul, K., Grahl, A., Sailer, U., Lanzenberger, R., ... Lamm, C. (2015). Context-sensitivity of the feedback-related negativity for zero-value feedback outcomes. *Biological Psychology*, 104, 184–192. doi:<https://doi.org/10.1016/j.biopsycho.2014.12.007>
- Philiastides, M. G., Biele, G., Vavatzanidis, N., Kazzner, P., & Heekeren, H. R. (2010). Temporal dynamics of prediction error processing during reward-based decision making. *Neuroimage*, 53(1), 221–232. doi:<https://doi.org/10.1016/j.neuroimage.2010.05.052>
- Pintzinger, N. M., Pfabigan, D. M., Pfau, L., Kryspin-Exner, I., & Lamm, C. (2017). Temperament differentially influences early information processing in men and women: Preliminary electrophysiological evidence of attentional biases in healthy individuals. *Biological Psychology*, 122, 69–79. doi:<https://doi.org/10.1016/j.biopsycho.2016.07.007>
- Platt, M. L., & Huettel, S. A. (2008). Risky business: The neuroeconomics of decision making under uncertainty. *Nature Neuroscience*, 11(4), 398–403. doi:<https://doi.org/10.1038/nn2062>
- Polezzi, D., Sartori, G., Rumiat, R., Vidotto, G., & Daum, I. (2010). Brain correlates of risky decision-making. *Neuroimage*, 49(2), 1886–1894. doi:<https://doi.org/10.1016/j.neuroimage.2009.08.068>
- Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128–2148. doi:<https://doi.org/10.1016/j.clinph.2007.04.019>
- Posner, M. I., Snyder, C. R., & Solso, R. (2004). Attention and cognitive control. In D. A. Balota & E. J. Marsh (Eds.), *Cognitive psychology: Key readings*. New York, NY: Psychology Press.
- San Martín, R. (2012). Event-related potential studies of outcome processing and feedback-guided learning. *Frontiers in Human Neuroscience*, 6, 304. doi:<https://doi.org/10.3389/fnhum.2012.00304>
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, 23(6), 695–703. doi:<https://doi.org/10.1111/j.1469-8986.1986.tb00696.x>
- Sherman, D. K. (2013). Self-affirmation: Understanding the effects. *Social and Personality Psychology Compass*, 7(11), 834–845. doi:<https://doi.org/10.1111/spc3.12072>
- Sherman, D. K., & Cohen, G. L. (2006). The psychology of self-defense: Self-affirmation theory. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 38, pp. 183–242). San Diego, CA: Academic Press.
- Sherman, D. K., & Hartson, K. A. (2010). Reconciling self-protection with self-improvement. In M. D. Alicke & C. Sedikides (Eds.), *Handbook of self-enhancement and self-protection* (pp. 128–151). New York: The Guilford Press.
- Simons, R. F. (2010). The way of our errors: Theme and variations. *Psychophysiology*, 47(1), 1–14. doi:<https://doi.org/10.1111/j.1469-8986.2009.00929.x>
- Smith, B. W., Mitchell, D. G., Hardin, M. G., Jazbec, S., Fridberg, D., Blair, R. J., & Ernst, M. (2009). Neural substrates of reward magnitude, probability, and risk during a wheel of fortune decision-making task. *Neuroimage*, 44(2), 600–609. doi:<https://doi.org/10.1016/j.neuroimage.2008.08.016>
- Steele, C. M. (1988). The psychology of self-affirmation: Sustaining the integrity of the self. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 21, pp. 261–302). New York: Academic Press.
- Summerfield, C., Behrens, T. E., & Koechlin, E. (2011). Perceptual classification in a rapidly changing environment. *Neuron*, 71(4), 725–736. doi:<https://doi.org/10.1016/j.neuron.2011.06.022>
- Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science*, 150(3700), 1187–1188. doi:<https://doi.org/10.1126/science.150.3700.1187>
- Tiedens, L. Z., & Linton, S. (2001). Judgment under emotional certainty and uncertainty: The effects of specific emotions on information processing. *Journal of Personality and Social Psychology*, 81(6), 973–988. doi:<https://doi.org/10.1037/0022-3514.81.6.973>
- Utku, H., Erzen, O. U., Cakmak, E. D., & Karakas, S. (2002). Discrimination of brain's neuroelectric responses by a decision-making function. *Journal of Neuroscience Methods*, 114(1), 25–31. doi:[https://doi.org/10.1016/S0165-0270\(01\)00519-2](https://doi.org/10.1016/S0165-0270(01)00519-2)
- Vazire, S. (2016). Editorial. *Social Psychological and Personality Science*, 7(1), 3–7. doi:<https://doi.org/10.1177/1948550615603955>
- Vecchio, R. P. (1990). Theoretical and empirical examination of cognitive resource theory. *Journal of Applied Psychology*, 75(2), 141–147. doi:<https://doi.org/10.1037/0021-9010.75.2.141>
- Wang, J., Novemsky, N., Dhar, R., & Baumeister, R. F. (2010). Tradeoffs and depletion in choice. *Journal of Marketing Research*, 47(5), 910–919. doi:<https://doi.org/10.1509/jmkr.47.5.910>
- Webb, C. A., Auerbach, R. P., Bondy, E., Stanton, C. H., Foti, D., & Pizzagalli, D. A. (2017). Abnormal neural responses to feedback in depressed adolescents. *Journal of Abnormal Psychology*, 126(1), 19–31. doi:<https://doi.org/10.1037/abn0000228>
- Wu, Y., & Zhou, X. L. (2009). The P300 and reward valence, magnitude, and expectancy in outcome evaluation. *Brain Research*, 1286, 114–122. doi:<https://doi.org/10.1016/j.brainres.2009.06.032>

- Yeung, N., & Sanfey, A. G. (2004). Independent coding of reward magnitude and valence in the human brain. *Journal of Neuroscience*, 24(28), 6258–6264. doi:<https://doi.org/10.1523/JNEUROSCI.4537-03.2004>
- Zhang, D., Gu, R., Broster, L. S., Jiang, Y., Luo, W., Zhang, J., & Luo, Y. J. (2014). Linking brain electrical signals elicited by current outcomes with future risk decision-making. *Frontiers in Behavioral Neuroscience*, 8, 84. doi:<https://doi.org/10.3389/fnbeh.2014.00084>
- Zhu, X., Gu, R., Wu, H., & Luo, Y. (2015). Self-reflection modulates the outcome evaluation process: Evidence from an ERP study. *International Journal of Psychophysiology*, 98(3 Pt 1), 389–393. doi:<https://doi.org/10.1016/j.ijpsycho.2015.08.001>
- Zhu, X., Zhang, H., Wu, L., Yang, S., Wu, H., Luo, W., ... Luo, Y. J. (2018). The influence of self-construals on the ERP response to the rewards for self and mother. *Cognitive Affective & Behavioral Neuroscience*, 18(2), 366–374. <https://doi.org/10.3758/s13415-018-0575-7>