Depressive states amplify both upward and downward counterfactual thinking

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ABSTRACT

Depression has been linked to counterfactual thinking in many behavioral studies, but the direction of this effect remains disputed. In the current study, the relationship between depression and counterfactual thinking was examined using the event-related potential (ERP) technique. In a binary choice gambling task, outcome feedback of the chosen option and that of the alternative option were both provided, so as to elicit the process of counterfactual comparison. By investigating ERP signals in response to outcome presentation, we discovered that when the fictive outcome was better or worse than the factual outcome, the amplitude of the P3 component was positively correlated with individual levels of depression, but not levels of anxiety. These results indicate that depression strengthens both upward counterfactual thinking and downward counterfactual thinking. The implication of this finding to clinical research is discussed.

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1. Introduction

Depression is a state of low mood associated with multiple psychophysiological symptoms including stress, anhedonia, and abnormalities in appetite and sleep (Krishnan and Nestler, 2008). High levels of depression give rise to biased thoughts and beliefs, such as negative self-image and self-focused attention (Beever et al., 2011). This effect may increase the risk for the development and recurrence of depressive disorder (Gotlib and Joormann, 2010). Therefore, investigating altered belief systems in depression has important implications for pathophysiological research.

The current study explores the relationship between depression and counterfactual thinking, which refers to the process of comparing reality and “what might have been” had a different decision been made (Coricelli et al., 2007). Comparisons based on alternatives that improve on reality (i.e., upward counterfactual) generate feelings of regret and disappointment (Mandel, 2003; Zeelenberg et al., 1998), while comparisons based on alternatives that worsen reality (i.e., downward counterfactual) generate feelings of rejoice and gratification (Galinsky et al., 2002; Medvec and Savitsky, 1997). The influence of depression on counterfactual thinking has been examined by many studies, but the precise nature of this influence is still debated. Markman and Miller (2006) reported that participants suffering from severe depressive symptoms generated counterfactuals that were less controllable (see also Eryilmaz et al., 2014; Monroe et al., 2005; Zhou and Kong, 2009). In contrast, depressed patients showed attenuated counterfactual thinking in Chase et al. (2010) (see also Quelhas et al., 2008). Finally, some studies have found no correlation between levels of depression and counterfactual thinking (e.g., Landman et al., 1995).

In our opinion, these heterogeneous findings may be attributable in part to methodological issues that distinguish some or all of those studies. First, most previous studies devoted to this topic have relied on self-report instrument rather than clandestine tools such as measures of brain activity (see Eryilmaz et al., 2014, for an exception). The limitations of these types of assessments are worth noting, including response bias and socially desirable responding (Crowley et al., 2009). Second, many studies estimate counterfactual thinking by asking retrospective questions (e.g., Markman and Miller, 2006), which may be vulnerable to the memory bias associated with depression (Bar, 2009). Finally, while most studies focus on the potential relation between depression and upward counterfactual which elicits feelings of regret, whether
depression affects downward counterfactual thinking in a decision-making scenario (e.g., Chase et al., 2010) with event-related potentials (ERPs) as a neural measurement. In this task, participants chose between two options and received positive or negative outcomes of the chosen option and the alternative option (Gu et al., 2011b; Yeung and Sanfey, 2004). Thus, the comparison between positive alternative outcome (AO) for short and negative chosen outcome (CO for short) elicits upward counterfactual thinking, while the comparison between negative AO and positive CO elicits downward counterfactual thinking (Giordetta et al., 2012). For instance, when a participant discovers that the option he/she selected led to monetary loss (CO) while the other option could have resulted in monetary gain (AO), he/she may feel regret and imagine the preferable alternate selection (upward counterfactual thinking). Two ERP components, the feedback-related negativity (FRN) and the P3, were chosen as they are the major biomarkers of outcome evaluation (Gehring and Willoughby, 2002; Yeung and Sanfey, 2004). Both components have been reported to be affected by depression levels (Proudfoot, 2015; Proudfoot et al., in press; Roschke and Wagner, 2003). Numerous studies have confirmed that both the FRN and the P3 are sensitive to the comparison between subjective expectation and reality (Hajcak et al., 2005, 2007; Wu and Zhou, 2009). In order to clarify the discrete roles played by these components in counterfactual contexts, Osinsky et al. (2014) recently proposed that the FRN indicates a binary categorization of gain versus no-gain for both CO and AO, while the P3 indicates motivational salience derived from counterfactual comparisons of CO and AO. Consistent with this idea, Liang et al. (2015) reveal that counterfactual comparisons manifest on the P3 rather than the FRN (see also Gu et al., 2011b; Wu and Clark, 2014). Accordingly, we suggest that the P3 elicited by the comparison between CO and AO reflects the process of counterfactual thinking when other major factors that could modulate this component (e.g., event probability, stimulus novelty, and task complexity; for reviews, see Polich, 2007; Polich and Criado, 2006) are controlled. We predicted that P3 amplitude in response to the comparison between CO and AO would increase as a function of individual differences in depressive traits, indicating a stronger tendency of counterfactual thinking among depressed individuals. In contrast, such associations would be absent for FRN amplitude.

2. Methods

2.1. Participants

20 right-handed Chinese students (11 females; mean age 22.75 years, SD = 1.68) from three universities in Tianjin participated in the experiment. All the participants were included in the final sample. All had normal or corrected-to-normal vision. None of the participants had sought medication for emotional problems before. All the participants denied regular use of any substance with the potential to affect the central nervous system. None had a history of neurological disease. None of the participants reported knowledge of the Cyrillic alphabet. All participants gave their informed consent prior to the experiment. The study was approved by the ethics committee of Academy of Psychology and Behavior, Tianjin Normal University.

2.2. Procedure

The task procedure replicated that of Gu et al. (2011b). Before the experiment, participants were informed about the rules and framework of the task and encouraged to respond so as to maximize the total score. Participants sat approximately 100 cm from a computer screen in an electrically shielded room. Each trial began with the presentation of two options represented as Cyrillic letters (“а” and “о” respectively), each of which was presented inside a white rectangle (2.51° × 2.51° of visual angle) appearing on either side of a fixation point. The position of these letters was counterbalanced across trials. Participants selected one option by pressing the “F” or “J” keys on the keyboard with left or right index finger, respectively. The selected rectangle was outlined in red for 500 ms. After that, the AO was presented in the unselected rectangle for 1000 ms simultaneously with the disappearance of the two letters. Then the AO faded away, leaving the rectangles and the fixation point on screen for 500 ms. Finally, the CO was presented in the chosen rectangle for 1000 ms. The formal task consisted of two blocks of 100 trials each. Stimulus display and behavioral data acquisition were conducted using E-Prime software 1.1 (PST, Inc., Pittsburgh, PA).

There were two kinds of outcome valence: positive (“+”) and negative (“−”). A positive and a negative CO indicated that participants gained or lost one point in the current trial, respectively (Fig. 1). Unbeknownst to the participant, no matter which option was chosen, the probability of receiving a positive or negative CO or AO in each trial was 50%. Moreover, the valences of AO and CO were independent of one another. Thus, we suggest that event probability, stimulus novelty, and task complexity have been controlled across conditions.

After participants finished the task, he or she was instructed to fill the Chinese version of Zung’s self-rating depression scale (SDS) and the trait form of Spielberger’s State–Trait anxiety inventory (STAI-T), both of which have demonstrated good internal consistency reliability, convergent validity, and discriminate validity (STAI-T: Shek, 1993; Spielberger et al., 1983; SDS: Shu, 1993; Zung et al., 1965). The STAI-T was included in this study in appreciation of the strong relationship between anxiety and depression (Stavvakaki and Vargo, 1986).

During debriefing, participants were informed that the outcomes were predetermined and there was no optimal strategy for the task. Accordingly, each participant was paid 30 Chinese Yuan (approximately 5 US dollars) for participation.

2.3. Electrophysiological recording and preprocessing

The EEG activity was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan, Inc., Herndon, VA), with an online reference to the left mastoid and off-line algebraic reference to the average of the left and right mastoids. Horizontal electrooculogram (EOG) was recorded from electrodes placed at the outer canthi of both eyes. Vertical EOG was recorded from electrodes placed above and below the left eye. All inter-electrode impedance was maintained at <5 k Ω. EEG and EOG signals were amplified with a 0.05–100 Hz bandpass filter and continuously sampled at 500 Hz/channel.

During the off-line analysis, ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software (Semlitsch et al., 1986). The EEG was digitally filtered through a zero phase shift, with 0.05–30 Hz band-pass filtering for the FRN and 2 Hz low-pass filtering for the P3 component (Gu et al., 2011a; Yeung and Sanfey, 2004). The data were then averaged into 1000 ms epochs (200 ms baseline) time-locked to outcome presentation. Any trials where EEG voltages exceeded a threshold of ±100 µV during the recording epoch were excluded from the analysis. After the artifact rejection processing, the numbers of trials survived in each condition were as follows: AO (+) CO (+): 45.63 of the 50 trials (91.26%); AO (−) CO (+): 44.84 (89.68%); AO (+) CO (−): 45.21 (90.42%); and AO (−) CO (−): 46.05 (92.10%).

2.4. Data analysis

The time windows for peak identification were determined through visual inspection of grand-averaged waveforms. The electrode at which the ERP components reached their maximum was detected along the
midline (Fz, FCz, Cz, CPz, Pz, POz and Oz); thereafter, the arithmetic mean of peak amplitudes of this electrode and 8 adjacent electrodes was calculated for further analysis (Gu et al., 2011a).

For all the analyses listed below, the significance level was set at 0.05. Post-hoc testing of significant main effects was conducted using the LSD method. Significant interactions were analyzed using simple-effects models. Statistical analysis was performed using SPSS 19.0 (IBM, Armonk, NY).

3. Results

3.1. Emotional scales

SDS score was 40.61 (SD = 7.70, range = 30–58) and STAI-T score was 40.50 (SD = 9.28, range = 24–62), respectively. The correlation between SDS and STAT-T was significant (r = .742, p < .001).

3.2. Behavioral results

Participants selected “а” and “е” 50.07% (SD = 12.44) and 49.45% (SD = 12.42) of the time, respectively. The averaged reaction time for decision-making was 0.90 s (SD = 0.94). None of these behavioral measures were correlated with SDS or STAI-T scores (ps > .05). Seeing that there was no optimal strategy in the task, the behavioral data were not analyzed further.

3.3. ERP results

3.3.1. Alternative outcome (AO, presented antecedently)

The ERP responses elicited by AO were entered into paired-samples t tests using AO valence (positive/negative) as the within-subject factor.

3.3.1.1. The FRN component. The FRN was measured as the most negative peak within the 200–400 ms time window. It was largest at electrode FCz (M = 2.80 μV, SD = 0.47 μV). Accordingly, the means of this electrode and 8 adjacent electrodes (F1, Fz, F2, FC1, FC2, C1, Cz and C2) were entered into further analysis. The main effect of AO valence approached significance (t(19) = 1.856, p = .079), with the FRN showed a tendency to be greater in response to positive AO than to negative AO (3.24 μV vs. 4.58 μV) (Fig. 2a). No significant correlation was detected between the FRN amplitude and personality scores (ps > .05).

3.3.1.2. The P3 component. The P3 was measured as the most positive peak within the 300–500 ms time window. It was largest at electrode CPz (M = 11.14 μV, SD = 1.08 μV). Accordingly, the means of this electrode and 8 adjacent electrodes (C1, Cz, C2, CP1, CP2, P1, Pz, and P2) were entered into further analysis. The main effect of AO valence was not significant (t(19) = 0.998, p = .331) (Fig. 2c). No significant correlation was detected between the P3 amplitude and personality scores (ps > .05).
3.3.2. Chosen outcome (presented subsequently)

The ERP responses elicited by CO were entered into 2 (CO valence: positive/negative) × 2 (AO valence: positive/negative) ANOVAs.

3.3.2.1. The FRN component. The FRN was measured as the most negative peak within the 200–400 ms time window. It was largest at electrode FCz (M = 4.95 μV, SD = 0.75 μV). Accordingly, the means of this electrode and 8 adjacent electrodes (F1, Fz, F2, FC1, FC2, C1, Cz, and C2) were entered into further analysis. The main effect of CO valence was significant (F(1, 19) = 29.705, p < .001); the FRN was greater in response to negative CO than positive CO (3.35 μV vs. 7.38 μV). The main effect of AO valence was also significant (F(1, 19) = 14.893, p < .005); the FRN was greater when following negative AO than positive AO (4.39 μV vs. 6.34 μV). The AO × CO interaction was insignificant (F(1, 19) = 0.893, p = .356) (Fig. 3a). No significant correlation was detected between the FRN amplitude and personality scores (ps > .05).

3.3.2.2. The P3 component. The P3 was measured as the most positive peak within the 300–500 ms time window. It was largest at electrode CPz (M = 17.13 μV, SD = 1.37 μV). Accordingly, the mean amplitudes of this electrode and 8 adjacent electrodes (C1, Cz, C2, CP1, CP2, P1, Pz, and P2) were entered into ANOVA analysis. The main effect of CO valence approached significance (F(1, 19) = 3.795, p = .066); positive CO showed a tendency to elicit a larger P3 compared to negative CO (11.76 μV vs. 10.92 μV). The main effect of AO valence was significant (F(1, 19) = 23.429, p < .01); the CO elicited a larger P3 when it was preceded by positive AO than negative AO (12.44 μV vs. 10.24 μV). The AO × CO interaction was also significant (F(1, 19) = 21.561, p < .01); the influence of AO on P3 amplitude was significant (F(1, 19) = 37.711, p < .0001) when CO was positive, but was insignificant when CO was negative (F(1, 19) = 0.536, p = .473) (Fig. 3c). The means and standard deviations of the P3 amplitude and latency in each condition are presented in Table 1.

Pearson correlation analysis revealed significant correlations between SDS scores and P3 amplitude when positive CO followed negative AO (r = 0.457, p < .05) and when negative CO followed positive AO (r = 0.462, p < .05). In brief, participant’s level of depression was correlated with the P3 component when the valences of AO and CO were different (Fig. 4). No significant correlation was detected between the P3 amplitude and STAI-T scores.

To assess the unique contributions of depression, a linear regression analysis was performed (see Foti and Hajcak, 2009, for similar methods). When entering both SDS and STAI-T scores to predict the P3 amplitude elicited by positive CO following negative AO, the regression coefficient for depression was significant (β = 0.377, p < .05) but anxiety was not (β = −0.168, p > .05); the same was true in the condition of negative CO following positive AO, such that depression (β = 0.462, p < .05), but not anxiety (β = 0.290, p > .05), was a significant predictor.

4. Discussion

Previous studies have argued about whether and how depression is associated with counterfactual thinking (e.g., Chase et al., 2010; Markman and Miller, 2006). Using the ERP technique, the current study investigated this issue in a trial-by-trial decision-making task. The ERP results reveal that individual depressive level was positively correlated with the amplitude of the P3 component elicited by chosen outcome presentation in two conditions. Specifically, the correlations were significant when a positive CO appeared after a negative AO (i.e., the real outcome was better than the alternative) and when a negative CO appeared after a positive AO (i.e., the real outcome was worse than the alternative). As indicated in the Section 1, these two conditions represent situations that motivate downward and upward counterfactual thinking, respectively. According to Osinsky et al. (2014), the P3 but not the FRN is involved in counterfactual comparisons (see also Liang et al., 2015). This idea is confirmed in the current study, such that the P3 rather than the FRN showed a significant interaction between AO and CO. We suggest that the current ERP findings indicate that depressive participants were more likely to be engaged in counterfactual thinking than their non-depressive counterparts. Presumably, this phenomenon is linked to the observation that depressed individuals are more susceptible to irrelevant thoughts and have more difficulty “getting over it” and refocusing on upcoming challenges (Lepore et al., 1996; Monroe et al., 2005). In addition, extravagant counterfactual thinking accounts for overgeneral memory bias and imagination (Markman et al., 1995; Miller and Taylor, 1995), which contributes to severe depressive illness (Meyers et al., 2006; Ridout

Table 1

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>P3 amplitude mean (SD)</th>
<th>P3 latency mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO (+)</td>
<td>7.56 μV (3.01)</td>
<td>398.31 ms (49.88)</td>
</tr>
<tr>
<td>AO (−)</td>
<td>7.18 μV (3.56)</td>
<td>392.29 ms (67.53)</td>
</tr>
<tr>
<td>AO (+) CO (+)</td>
<td>14.20 μV (5.13)</td>
<td>400.29 ms (41.53)</td>
</tr>
<tr>
<td>AO (−) CO (+)</td>
<td>9.32 μV (3.85)</td>
<td>353.74 ms (58.18)</td>
</tr>
<tr>
<td>AO (+) CO (−)</td>
<td>10.07 μV (4.02)</td>
<td>383.92 ms (49.43)</td>
</tr>
<tr>
<td>AO (−) CO (−)</td>
<td>11.17 μV (4.88)</td>
<td>438.48 ms (49.86)</td>
</tr>
</tbody>
</table>
One might suggest that our major findings could be explained in terms of the occurrence of an unexpected outcome rather than counterfactual thinking. We disagree with this opinion for two reasons. First, the indication suggests that depressed participants were more surprised when the valences of AO and CO were different. However, this was unlikely because AO and CO valences were independent of one another during the task (see Section 2). Second, numerous studies suggest that the FRN labels the violation of outcome expectancy (e.g., Bellebaum and Daum, 2008; Nieuwenhuis et al., 2004; Pfabigan et al., 2011), but its amplitude was insensitive to either the AO × CO interaction or levels of depression in this study. Instead, we interpret the P3 findings in light of Osinsky et al. (2014) and suggest that this component was involved in counterfactual comparisons between chosen and unchosen outcomes (see also Liang et al., 2015).

Most previous studies have concentrated on the impact of depression on upward counterfactual thinking, inferring that depressive symptoms might be associated with stronger feelings of regret (Monroe et al., 2005). However, the current study indicates that levels of depression are related to both upward and downward counterfactual thinking. That is, people who suffer from depressive symptoms are more likely to think about "what would have happened" regardless of the valence of current outcomes. In our opinion, this phenomenon may have its root in abnormalities of neural systems. Coricelli et al. (2005) have linked the process of counterfactual comparison to a number of brain regions, including the medial temporal cortex (see also Coricelli et al., 2007). It is possible that a hyperactive medial temporal cortex could result in depressive individuals' tendency to counterfactual thinking. The current study has not included EEG source localization owing to its unreliable spatial accuracy (Zhukov et al., 2000). However, many brain-imaging studies have found stronger medial temporal activation in major depressive disorder (Beauregard et al., 1998; Kumari et al., 2003), which may support our idea.

Finally, the inconsistency between the current findings and previous studies needs to be addressed. A series of studies conducted by Proudfit and colleagues have revealed that the FRN, rather than the P3, was associated with depression, such that the FRN amplitude was inversely related to depression scores (e.g., Bress et al., 2013; Foti and Hajcak, 2009; Foti et al., 2011; for reviews, see Proudfit, 2015; Proudfit et al., in press; but see Mueller et al., 2005), which contradicts our current findings. We suspect that this inconsistency occurred because in those studies, participants were only aware of the outcome associated with their decisions; thus, they did not engage in counterfactual thinking (Proudfit, 2015). As an alternative explanation, previous studies focusing on outcome evaluation have suggested that the FRN and P3 represent quick detection and deliberate evaluation of the current event, respectively (Gu et al., 2011a; Philiaestides et al., 2010; Wu and Zhou, 2009). Therefore, the preeminence of the P3 in the current study may have resulted from the outcome information being relatively complicated and requiring more deliberate thinking, while the FRN effect would manifest where the outcomes were simple and easy to capture. Finally, the relationship between depressive symptoms and ERP signals with regard to outcome evaluation may be unstable for non-clinical samples. In any case, further investigation is necessary to clarify this issue.

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