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Gratitude intervention modulates P3 amplitude in a temporal discounting task☆

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ABSTRACT

Gratitude has been shown to reduce economic impatience. In particular, individuals induced to experience heightened gratitude are more willing to choose delayed larger rewards over immediate smaller rewards (i.e., they have lower discounting rates) than those in a neutral condition. Using the event-related potential (ERP) method, we investigated the relation between gratitude level and neurophysiological correlates. Of interest was motivated information processing, as indexed by the P3 component. Participants were administered a gratitude or a neutral mood induction followed by a temporal discounting task (choosing between a fixed immediate reward versus a future reward that varied across trials) while electroencephalogram (EEG) activity was recorded. Individuals in the gratitude condition had greater P3 amplitude, suggesting greater attention to the future-reward option (the choice option that varied across trials), even when this option was not selected, and providing the first evidence of gratitude-induced changes in electrophysiological activity.

1. Introduction

1.1. Temporal discounting

People are often faced with choices between immediate and future benefits and costs, referred to as intertemporal decisions (Frederick et al., 2002). Classic examples include deciding how much of one's earnings to spend now versus to put in a retirement account for the future; making recycling choices that might be less convenient in the moment but that improve the long term health of the community; or choosing between an immediately available item for purchase and a superior option that will not be available for several weeks, such as a new car in one's preferred color. In a common experimental paradigm, one might be offered choices between "$10 immediately versus $20 in a week" or "$15 in a week versus $18 in a month." In these types of decisions, the subjective value of a reward (or a loss, but the focus here is on rewards) decreases as a function of delay in its receipt. This phenomenon is known as *temporal discounting*. Discounting can be further quantified in terms of the rate at which subjective value declines over time. Discounting research was developed in a seminal work by Ainslie (1975), and remains a key area of decision research (see Urminsky and Zauberman, 2016, for recent review). It also has implications for psychological conditions such as depression and anxiety, and for pathological personality traits such as impulsiveness (e.g., Hartley and Phelps, 2012; Xia et al., 2017).

One particularly striking characteristic of human temporal decision making is the overwhelming preference that people show for immediate rewards, often referred to as a *present bias* (O'Donoghue and Rabin, 1999). Higher rates of individual discounting, including a greater preference for immediate rewards, have been associated with a wide range of measures of well-being and life success including poorer academic performance (Kirby et al., 2005; Reimers et al., 2009), psychopathology (e.g., Pinto et al., 2014; Pulcu et al., 2014), deficits in social functioning (Hirsh et al., 2008), poor economic choices (Chabris et al., 2008; Meier and Sprenger, 2010), and less healthy behaviors (e.g., Chapman et al., 2001; MacKillop et al., 2011). Consistent with these negative outcomes, greater discounting is often referred to as *impatient* or *impulsive* discounting behavior. While some discounting is considered rational from an economic perspective (Loewenstein and Prelec, 1992; Samuelson, 1937), it is important to develop tools to help individuals reduce impatience when their temporal choices routinely lead to non-adaptive and unhealthy outcomes.

There are likely many factors that contribute to discounting behavior. In one framework, immediate-reward options are assumed to elicit automatic affective responses that appeal to short-term goals and produce an urge to select this option (e.g., eating a piece of cake now vs.

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losing weight in a month; e.g., Metcalfe and Mischel, 1999; Soman et al., 2005). This approach emphasizes that cognitive effort is required to control the prepotent affective response so that both choice options can be evaluated more fully (Shiv and Fedorikhin, 1999). A complementary framework emphasizes the decision maker's mental representation of choice options, time delay, and goals (Malkoc and Zaubermann, 2006). In this framework, discounting is attributed, in part, to differences between options in terms of level of abstraction, sensory quality, and affect elicited. Manipulations that impact how the options are represented (e.g., increasing affective qualities of the future-reward option) reduce discounting (e.g., Malkoc et al., 2010; Zhao et al., 2007). Discounting is also related to time perception and to beliefs about the likelihood of receipt of promised future rewards (Worthy et al., 2014). One common theme is that greater discounting is often associated with decreased processing of future-reward options relative to more immediate-reward options.

Individual differences relevant to psychopathology including several personality traits and cognitive skills have also been linked to discounting behavior. Trait impulsivity, a predisposition towards acting prematurely and without foresight (Dalley et al., 2011), has been associated with a higher rate of discounting, though findings are mixed (de Wit et al., 2006; Koff and Lucas, 2011; Ostaszewski, 1996; Sripada et al., 2011; but see Martin and Potts, 2009; Reynolds et al., 2006), leaving open whether there is a relationship between self-report scaled-based and behavioral choice-based measures of impulsivity. Additionally, trait anxiety (Xia et al., 2017) and other traits involving negative emotional arousal such as neuroticism (Hirsh et al., 2008; Manning et al., 2014) and sadness (Lerner et al., 2012) have been associated with a higher rate of discounting. In contrast, a lower rate of discounting is found in those with strong numeracy skills (Benjamin et al., 2013; Frederick, 2005), and with high cognitive functioning more generally (Kirby et al., 2005; Shamosh and Gray, 2008; Weatherly and Ferraro, 2011; but see Manning et al., 2014). In general, heightened affective processing has been linked to increased discounting, while high cognitive functioning has been associated with reduced discounting, suggesting that the balance of cognition-emotion interaction plays a role in discounting.

Recently, gratitude has been proposed as a potential tool for promoting patience in temporal decision making (DeSteno, 2018). Gratitude is a positive emotion one feels when another person has given, or attempted to give, one something of value and, more generally, is an attitude of thankfulness and appreciation of life and the positive in the world (Emmons and McCullough, 2004; see Wood et al., 2010, for review). In a central study, DeSteno et al. (2014) induced gratitude through a short exercise in which participants wrote about an experience that made them feel grateful. In control conditions, participants instead wrote about an experience that made them feel happy or about a typical day. In a decision task, those in the gratitude condition discounted less than those in control conditions, making more future-reward choices. That the happiness induction (i.e., another affect with positive valence) did not also reduce discounting illustrated the specificity of the relationship between gratitude and discounting. Further evidence was presented in later work in which lower rates of monetary discounting were found among individuals with chronically elevated gratitude in everyday life (Dickens and DeSteno, 2016). How gratitude reduces discounting is not clear, but gratitude inductions have also been found to promote prosocial behaviors over self-interested ones in other tasks (Bartlett and DeSteno, 2006; Bartlett et al., 2012; DeSteno et al., 2010; Nowak and Roch, 2007), and to produce positive affect and well-being (including reducing anxiety and worry; e.g., Lau and Cheng, 2011; Ramirez et al., 2014; Watkins et al., 2003), suggesting ways in which gratitude might influence decision making. The research is also promising in terms of possible broad benefits of gratitude interventions for improving overall well-being.

1.2. Gratitude, individual differences, and P3

In the present work, we investigated the electrophysiological correlates of the relationship between induced gratitude and discounting using event-related potential (ERP) methodology with a focus on the ERP component known as the P3. The P3 is a positive deflection in the EEG waveform that typically occurs ~300 ms after a stimulus presentation with maximal amplitude at the brain's midline over the parietal lobe (Sutton et al., 1965). The P3 is a measure of central nervous system activity that reflects the processing of incoming information (see Polich, 2007, for review). A traditional P3-eliciting task is an “oddball” paradigm where one is prompted to respond to an infrequent target stimulus (e.g., a high pitched tone) occurring in a background of frequent stimuli (e.g., low pitched tones; e.g., Donchin et al., 1978). In this task, P3 amplitude is greater for target relative to non-target stimuli. While the meaning of the P3 is not fully understood, P3 activity is highly sensitive to the motivational significance of the stimulus (Begleiter et al., 1983; Kok, 2001; Polich and Kok, 1995), defined as having central relevance to the task (see Nieuwenhuis et al., 2005, for review). P3 activity is also sensitive to stimulus components that are not task-relevant but may be related to broader motivational goals. For example, emotional stimuli elicit a larger P3 than neutral stimuli, even when emotional content is not task-relevant (Schupp et al., 2003). Additionally, P3 activity is modulated by the amount of attention paid to the stimulus, with activity emerging when a stimulus is attended to but not when it is intentionally ignored or when attention is occupied by a dual task (Donchin and Cohen, 1967; Duncan-Johnson and Donchin, 1977; Hillyard et al., 1973). Overall, P3 activity is thought to reflect stimulus evaluation, and the degree to which or quality with which that information is actively processed (Polich and Herbst, 2000).

The P3 has been elicited with presentation of subjective-choice alternatives in decision making tasks in only a few studies. In a discounting study by Li et al. (2012), simultaneous presentation of a novel immediate- and future-reward choice stimuli elicited a P3 (maximal at electrode Pz). Some types of choice characteristics appear to elicit a larger P3 than others. This is shown in a different type of subjective decision making task in which individually presented gambles involving risk (e.g., a 75% chance of gaining $100) elicited larger P3s than those involving ambiguity (e.g., an unknown chance of gaining $100), and individuals were more likely to play the risky gambles (Wang et al., 2015). There is also evidence of individual differences in the extent to which a choice characteristic is associated with a larger (or smaller) P3. In a discounting study by Xia et al. (2017), individuals were presented with choice options one at a time prior to decision making. Individuals high in trait anxiety had larger P3s in response to immediate-reward options (whether or not this option was ultimately selected on an individual trial) while individuals low in trait anxiety had larger P3s in response to presentation of future-reward options. More anxious individuals were also more likely to select immediate-reward options relative to those lower in anxiety. In general, a large P3 amplitude has been most often associated with an individual's dominant preference.

No known studies have considered differences in P3 amplitude in a discounting task as a function of a gratitude manipulation. The present experiment involved a brief writing-based gratitude or neutral mood induction task (which will be referred to here as a gratitude manipulation), modeled after DeSteno et al. (2014), followed by a 240-trial temporal discounting task. The discounting task procedure most commonly used in behavioral studies is one in which immediate- and future-reward options, presented simultaneously, both vary across trials (e.g., Li et al., 2012). However, such a procedure poses difficulties for interpretation of P3 activity because, among other reasons, P3 activity could be elicited by either or both choice options. One alternative procedure, the one we use here, is one in which the immediate-reward option is held constant and only the future-reward option changes

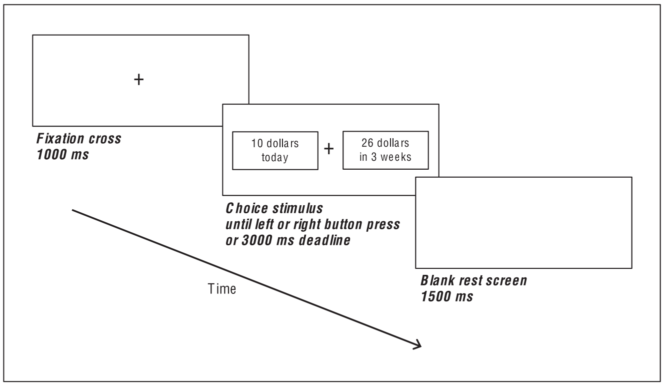

Fig. 1. Example of a delay discounting choice in which one must select a preference between the immediate smaller reward (at left) and the future larger reward (at right). The immediate reward remained constant across trials while the future reward varied across trials in dollar value and in length of delay period.

across trials (following Kable and Glimcher, 2007; see Fig. 1). With this approach, even though both choice options are presented simultaneously, stimulus-driven electrophysiological activity can be attributed more directly to the processing of one of the options – in this case, the future-reward option.

Our focal question was whether manipulated gratitude, which has been previously shown to lead to increased selection of the future-reward option, also influences P3 amplitude for the future-reward option. We predicted greater P3 amplitude among gratitude-induced individuals (relative to neutral controls) expected individuals with greater P3 amplitude to be those with lower rates of discounting in general. A finding of increased P3 activity among individuals with heightened gratitude would provide evidence that this affective state enhances processing of future-reward options, and would demonstrate the use electrophysiological methods to further establish the role of gratitude in altering stimulus evaluation of future-reward choice options. Further, given only a few studies illustrating a P3 in subjective decision contexts, findings from the present study could strengthen evidence for the relationship between P3 amplitude for a choice stimulus and general preference for that type of stimulus across trials. In other words, the study has the potential to show P3 amplitude for the future-reward option to be an index of preference for this type of option across trials (as reflected in one's rate of discounting).

At the end of the present study, trait and state anxiety, trait impulsivity, and numeracy scale measures were also administered. P3 amplitude has generally been found to be lower for individuals higher in trait impulsivity in a variety of simple cognitive tasks, largely across types of stimuli (e.g., oddball task; Harmon-Jones et al., 1997; Russo et al., 2008; De Pascalis et al., 2004) but this finding has not been established in subjective decision contexts (see Martin and Potts, 2009). As introduced earlier, there is some evidence that trait anxious individuals show reduced P3 amplitude for future-reward options (Xia et al., 2017). For numeracy, more numerate individuals have been shown to have larger amplitudes on multiple ERP components associated with magnitude judgment (see Dehaene, 1996: Paulsen et al., 2010), but we know of no studies that speak to the relationship between numeracy, subjective choice behavior, and P3 activity. In the present study, despite these limited or mixed past findings, we considered whether there might be greater P3 amplitude among individuals low in trait impulsivity and anxiety, and we considered whether there might be greater P3 amplitude among individuals high in numeracy. Additionally, we evaluated interactions between condition and other measures to assess whether the gratitude intervention might be particularly effective (or ineffective) in modulating P3 amplitude for individuals high in trait impulsivity and anxiety.

2. Method

2.1. Participants

A total of 108 university undergraduates (47 men and 61 women; 12 left-handed) volunteered in exchange for introductory psychology course credit. The study was approved by the university's Institutional Review Board, and all participants gave their written consent prior to participation. Participants were randomly assigned to either a Neutral ($n = 53$) or Gratitude ($n = 55$) condition, with the experimenter blind to assignment. Participants were run individually in two-hour sessions in which they participated in several studies. After exclusion of a number of participants due to EEG noise or to an insufficient number of trials of one of the response types (immediate-reward choice or future-reward choice; see Results section for details), 84 participants (34 men and 50 women; 7 left-handed) remained, with 40 participants in the Neutral condition and 44 participants in the Gratitude condition. A power analysis indicated $N = 84$ to be the sample size needed to replicate the behavioral gratitude effect on discounting ($d = 0.62$; DeSteno et al., 2014) with a power of 0.80. Thus, the size in the final sample used in analyses here was sufficient for replication. We also reran all behavioral analyses with $N = 103$ participants (all participants except the 5 for which there was EEG noise), with no change in findings, as we indicate in the Results section.

2.2. Procedure

Participants completed the mood induction task, the temporal discounting task, and a subsequent standard battery of individual difference scales in the order presented below. However, participants were instructed on and given practice trials for the temporal discounting task before they completed the gratitude intervention task. This was done in order to maximize any effect of the induction task by minimizing interaction between participant and experimenter between the induction and discounting tasks. Participants were fit with an electrode cap at the outset of the study, EEG recordings were made during the temporal discounting task only, and the cap was removed before scales were administered at the end of the study.

2.2.1. Mood induction task

Following DeSteno et al. (2014), seated participants were prompted by instructions on a computer screen to recall the events of a typical, generic past day (Neutral condition), or to recall an event that made them feel grateful (Gratitude condition), and to spend 5 min typing their recollection in detail. Immediately following the written mood induction task, participants completed a computerized state affect measure consisting of several descriptors (again following DeSteno et al.), intended as a manipulation check. Participants indicated on a 5-point scale (1 = *not at all*, 5 = *very much*) how much their current state could be described by 17 affective descriptors (e.g., *happy*, *bored*, *confident*). Gratitude level was operationalized as the mean response to the *grateful*, *appreciative*, and *thankful* descriptors. Happiness was operationalized as the mean response to *happy*, *content*, and *pleasant*, and was included here only to assess the manipulation's specificity.

2.2.2. Temporal discounting task

Each participant was presented with 120 unique choices, which were subsequently repeated in a different order for a total of 240 trials (task procedure adapted from Li et al., 2012; McClure et al., 2007; Oswald and Sailer, 2013). Each participant saw the trials on a computer screen in one of four randomized orders. All of the choices were between receiving $10 today (on the left side of the display; see Fig. 1) and a larger amount of money in the future (on the right side of the display; all rewards were hypothetical). The magnitude of the future reward varied over 12 amounts: $11, $12, $13, $14, $15, $16, $25, $26, $27, $28, $29, and $30. The delay of the future reward varied over

10 levels: 1, 2, 3, 4, 5, 12, 13, 14, 15, and 16 weeks (12 amounts × 10 delay levels = 120 trials). Magnitude and delay values were selected so that the future reward option would be chosen approximately half of the time on average across participants (see Oswald and Sailer, 2013).

As shown in Fig. 1, each trial consisted of a 1000 ms fixation cross followed by presentation of a choice stimulus. A 3000 ms response window started at the same time as the presentation of the stimulus. As soon as a response was given (or at the end of 3000 ms if this came first), the stimulus was replaced with a blank rest screen for 1500 ms before the next trial began. Participants were instructed that they could choose the immediate choice with their left index finger, which was to be placed over the leftmost button on the response box, or the future choice with their right index finger, which was to be placed over the rightmost button. Both buttons were black, and all other buttons were covered with white paper. Participants were asked to focus on the fixation cross to avoid excessive eye movement, and were given a 2-min rest break after each set of 60 trials. Before performing the primary task, participants completed a set of 12 practice trials that used smaller dollar values than the actual trials (e.g., $1 today or $2 in 1 week). Participants were given the opportunity to ask questions and, if needed, to repeat the practice trials until they understood the task.

2.2.3. Scale measures

Participants completed a standard battery of individual difference scales on the computer. Of interest here were three scales: Barratt's 30-item Impulsiveness Scale (BIS; Patton et al., 1995) with subscales of motor (BIS-M), attentional (BIS-A), and nonplanning (BIS-NP) impulsiveness; a 40-item State/Trait Anxiety Index (STAI; Spielberger et al., 1983) with separate measures for state (STAI-S) and trait (STAI-T) anxiety; and an 8-item Abbreviated Numeracy Scale (abbreviated NUM here; Weller et al., 2013) measuring one's ability to understand, manipulate and use numerical information. BIS and STAI responses were elicited on a 1–4 Likert scale, with larger numbers indicating greater item endorsement. The average of responses to relevant items, after appropriate reverse coding, was computed separately for each scale or subscale. The NUM contains free-response problems, and score was computed as the number of problems answered correctly.

2.2.4. EEG recording and data processing

EEG recordings were collected using a 64-channel cap (Cortech Solutions, Wilmington, NC), and the BioSemi ActiveTwo system (BioSemi, Amsterdam, Netherlands), with electrode sites arranged based on the 10–20 System. During offline processing, all data were referenced to the average of the two electrodes placed on left and right mastoids. Eye movements and blinks were recorded from two electrodes placed around each eye (four total). Specifically, an electrode was placed 1 cm outside of each eye to record horizontal eye movements, and another electrode was placed 1 cm below each eye to record vertical eye movements. EEG data was collected using a sampling rate of 1024 Hz and input was filtered with a low-pass 100 Hz filter and a high-pass 0.16 Hz filter. The signal was amplified by a gain of 1 at each electrode.

BrainVision Analyzer (Brain Products GmbH, Munich, Germany) was used to process data offline. Data were first re-referenced to the average of the left and right mastoid electrodes. They were then filtered with Butterworth zero phase filters with a low cutoff of 0.1 Hz, a high cutoff of 30 Hz, and a maximal slope of 24 dB/oct. Discounting task trials were segmented into stimulus-locked epochs from 200 ms before to 1000 ms after stimulus presentation. The Gratton and Coles algorithm (Gratton et al., 1983) was used to perform ocular corrections. Baseline correction for stimulus-locked epochs was performed using the 200 ms period immediately prior to stimulus presentation. Artifacts were detected and rejected through automatic inspection, with segments falling outside of these parameters automatically marked for rejection: a maximal voltage step of 75 μV/ms, a maximal difference of 175 μV between the highest and lowest points in an interval of 400 ms, and activity below 0.5 μV for 100 ms. Individual channel mode was used.

3. Results

3.1. Data rejection

To obtain an acceptable signal to noise ratio, Luck (2014) and Woodman (2010) suggest ~30–60 trials per response type per participant as a rule of thumb for large waveforms (such as the P3) with fewer trials possible in contexts with minimal noise and attentive participants. With these standards in mind, and with the goal of maintaining the largest sample size for data analysis without compromising ERP data quality at the individual level, we set an a priori cutoff of 20 trials. That is, participants were excluded from all analyses if there was significant EEG noise during recording or if fewer than 20 EEG trials could be analyzed per response type. We excluded the participants from both the behavioral and the ERP analyses (even though the exclusions were for the integrity of the ERP analyses) for evaluation of and interpretation of findings across types of data.

Five participants were immediately excluded from all analyses due to EEG noise. A total of 19 additional participants were excluded due to having an insufficient number of trials (< 20 trials) in which the immediate-reward choice was selected (9 participants; 4 from Gratitude condition) or in which the future-reward choice was selected (12 participants; 6 from Gratitude condition), i.e., extreme choice patterns. These excluded participants were lower in state anxiety than included participants ($M = 1.8$ vs. 2.2 respectively; $t(106) = 2.71$, $SE = 0.14$, $p = .008$), but otherwise did not differ. Data from 84 participants were analyzed and reported here. However, to assess whether the behavioral findings were dependent on the subset of data used, we also re-ran all analyses using all participants except the 5 with EEG noise, for a total of $N = 103$ participants. There were no differences in patterns of findings or statistical analyses with the larger data for either the behavioral or the ERP findings. In other words, limiting the set of participants did not change the results or interpretation in any way.

3.2. Gratitude manipulation and scale scores

Descriptive statistics for scales are shown in Table 1 and correlations between scales are in Table 2. Scores were approximately normally distributed (|skewness| < 1). Participants in the Gratitude condition had higher self-reported gratitude ($M = 4.3$, $SD = 0.72$, range = 2.67–5.00) than those in the Neutral condition ($M = 3.9$, $SD = 1.10$, range = 1.33–5.00); $t(82) = -2.46$, $SE = 0.20$, $p = .016$), but did not have higher self-reported happiness ($M = 3.4$ vs. 3.3 for Gratitude and Neutral conditions respectively; $t(82) = -0.77$, $SE = 0.21$, $p = .442$), evidence that the manipulation selectively increased state gratitude as intended. However, the difference in means was smaller than in DeSteno et al. (2014), where the means were 4.8

Table 1
Descriptive statistics for individual difference measures.

	M	*SD*	Range	Skewness
Attentional impulsiveness (BIS-A)	2.23	0.49	1.38–3.63	0.68
Motor impulsiveness (BIS-M)	1.93	0.36	1.18–2.91	0.33
Nonplanning impulsiveness (BIS-N)	2.10	0.40	1.27–3.09	0.31
Trait anxiety (STAI-T)	2.31	0.54	1.20–3.75	0.32
State anxiety (STAI-S)	2.23	0.63	1.20–3.95	0.61
Numeracy (NUM)	5.65	1.34	1.00–8.00	−0.52
Hyperbolic discount factor (*k*)	0.62	0.39	0.002–1.57	0.39

$N = 84$. *Notes*: BIS, STAI-T and STAT-S were on a 4-point scale; and NUM can range from 0 to 8 correct responses; values closer to 0 on *k* indicate a lower rate of discounting. Values were within the expected ranges for a college student sample.

Table 2
Correlations between condition and individual difference measures.

	GEND	BIS-A	BIS-M	BIS-N	STAI-T	STAI-S	NUM	*k*
COND	−.06	.02	.16	−.03	.13	.01	.27*	−.07
GEND		.02	−.15	.05	.20	.11	−.22	−.01
BIS-A			.43***	.39***	.41***	.44***	.04	.07
BIS-M				.52***	−.11	−.13	.17	−.05
BIS-N					.19	.15	−.03	.08
STAI-T						.78***	−.07	.19
STAI-S							−.11	.31**
NUM								−.39***

Notes: For Condition, −1 = Neutral condition and 1 = Gratitude condition. For Gender, −1 = male and 1 = female.
*** $p < .001$.
** $p < .01$.
* $p < .05$.

Table 3
Linear regression for predicting *k* from condition and individual difference measures.

Model	B	*SE*	*β*	*t*	*p*
Constant	25.53	10.73		2.38	.020
COND	0.04	1.39	−0.14	0.03	.975
GEND	−1.75	1.36	0.00	−1.29	.203
BIS-A	−0.05	3.45	0.00	−0.01	.989
BIS-M	0.03	5.04	0.00	0.01	.996
BIS-N	1.13	4.02	0.04	0.28	.779
STAI-T	4.16	2.87	0.19	1.45	.152
NUM	**−3.27**	**0.89**	**−0.41**	**−3.69**	**< .001**

Notes: For overall model: $F(7,76) = 2.69$, $MSE = 135$, $p = .015$, $R^2 = .20$. With STAI-S in place of STAI-T: **STAI-S *B* = 7.32, *SE* = 3.29, *β* = 0.38, *t* = 2.23, *p* = .029**. In separate analysis adding all two-way interactions with COND, no interactions were statistically significant (*p*s > .100 except COND × GEND $p = .061$). In an alternative separate analysis adding a two-way interaction between NUM and STAI-S, the latter was not statistically significant ($p > .100$). Boldface indicates statistically significant predictors.

($SD = 0.38$) versus 3.0 ($SD = 1.04$) for the Gratitude and Neutral conditions respectively, which could reduce the condition effect on behavior. Surprisingly, condition was also correlated with numeracy, with numeracy scores in the Gratitude condition ($M = 6.05$, $SD = 1.51$, range = 2–8) higher than those in the Neutral condition ($M = 5.23$, $SD = 1.49$, range = 1–8; $t(82) = -2.50$, $SE = 0.33$, $p = .014$). It is possible that the participants assigned to the Gratitude condition were more numerate, or alternatively it might be that the gratitude induction led to better performance on the numeracy task perhaps as a result of focusing attention, consistent with suggestive evidence of math performance improvements with a mindfulness intervention (Schonert-Reichl et al., 2015).

3.3. Temporal discounting behavioral responses

3.3.1. Choice behavior

Participants gave a response to an average of 238 out of 240 trials ($SD = 2.5$, range = 223–240). Across repeated stimuli, participants gave the same response a mean of $M = 86\%$ ($SD = 8$, range = 50–98) of the time when a response was given, indicating high reliability. Immediate-reward choices were given $M = 150$ times ($SD = 47$, range = 29–207) and future-reward choices were given 88 times ($SD = 47$, range = 33–211). The average percentage of immediate-reward choices was 63% ($SD = 20$, range = 12–86). A hyperbolic discount factor (k) was estimated using a modified version of DeSteno et al. (2014) Matlab program. This estimation process assumes a hyperbolic discount function, where dollar value is multiplied by $1/(1 + k * \text{days of delay})$ to predict discounted value, a function that well describes human behavior (Mazur, 1987; Myerson and Green, 1995).[1] Values of k can range from 0 to infinity, where a number closer to 0 indicates less discounting. Here, the mean k was 0.62 ($SD = 0.39$, range = 0.002–1.57) and was highly correlated with percentage of immediate choices made ($r = .90$). There were no differences in choices made in the first versus the second half of trials, with the exception that the total number of trials completed was slightly higher in the second half than in the first ($M = 119.6$ vs. 119.0 respectively; $t(83) = -3.16$, $SE = 0.20$, $p = .002$).

3.3.2. Response times

There were no reliable difference in RTs for immediate-reward ($M = 1056$ ms, $SD = 234$, range = 542–1641) relative to future-reward choices ($M = 1080$ ms, $SD = 227$, range = 459–1624; $t(83) = -1.33$, $SE = 18$, $p = .187$). Average RT was not correlated with k, $r(82) = -.09$, $p = .434$. However, k was correlated negatively with response time for immediate-reward choice trials ($r(82) = -.26$, $p = .012$) and positively with response time for future-reward choice trials ($r(82) = .36$, $p = .009$). In other words, the more one discounted, the more quickly immediate-reward choices and the less quickly future-reward choices were made.

3.4. Relationship between gratitude manipulation and choice behavior

Unlike past work, gratitude did not influence choice behavior in that k did not differ between Gratitude ($M = 18$, $SD = 12$, range = 1.4–48) and Neutral ($M = 20$, $SD = 12$, range = 0.07–45) conditions, $t(82) = 0.66$, $SE = 2.72$, $p = .511$.[2] The value of k was correlated with numeracy, and state anxiety, as shown in Table 2. Similarly, in a linear regression with all predictors included in the model (see Table 3), only state anxiety and numeracy were reliable predictors of k. (Note that the model was run once with trait anxiety and once with state anxiety in its place because they are highly correlated, but only state anxiety was a reliable predictor.) In other words, we replicated a previously observed correlation between discounting and number skills (i.e., more numerate individuals discount less) and also found a correlation between discounting and state anxiety (i.e., more anxious individuals discount more). We did not find evidence of any relationship between discounting and trait impulsivity or trait anxiety (or, in a separate analysis, of an interaction between numeracy and state anxiety, $p > .100$). It is possible that state anxiety arose from use of ERP methods (e.g., participant unfamiliarity with electrodes, discomfort with physical contact) and had a greater impact on behavior relative to other predictors than might otherwise be observed. Response times did not differ between Gratitude ($M = 1012$ ms, $SD = 194$, range = 526–1354) and Neutral ($M = 1064$ ms, $SD = 238$, range = 525–1522) conditions, $t(82) = 1.10$, $SE = 47$, $p = .275$, and were not predicted by any individual difference measures.

3.5. ERP analyses

The P3 was characterized as the mean amplitude of the waveform at electrode Pz in the window from 275 to 375 ms after stimulus (see Fig. 1). Pz was selected a priori based on its status as the electrode of peak amplitude in related past work (e.g., Li et al., 2012). Correlations between individual difference measures and P3 amplitude are shown in Table 4, separately for trials on which the immediate-reward versus the future-reward response was given. There were no reliable differences in P3 activity between immediate-reward ($M = 7.54\,\mu V$, $SD = 4.73$,

[1] We also ran all analyses using an exponential discount function (see Berns et al., 2007, for discussion of both models). The findings do not change.

[2] The finding does not change if we control for self-reported gratitude in each condition before analyzing the correlation between condition and k ($p > .500$).

Table 4
Correlations between individual difference measures and P3 amplitudes.

	P3	
	Immediate	Future
COND	.21^	.18
GEND	.16	.20
BIS-A	−.17	−.14
BIS-M	−.10	−.17
BIS-N	−.16	−.12
STAI-T	−.25*	−.20
STAI-S	−.33**	−.34**
NUM	−.04	−.05
k	−.16	−.20

Note: A positive correlation indicates that as the individual-difference measure increases, P3 amplitude (in a positive direction) increases.
** $p < .01$.
* $p < .05$.
^ $p < .06$.

Table 5
Linear regression for predicting P3 amplitude from condition and individual difference measures.

Model	B	*SE*	*β*	*t*	*p*
(Constant)	12.73	4.34		2.91	.004
COND	**2.99**	**1.00**	**0.33**	**2.98**	**.004**
GEND	**2.00**	**0.99**	**0.22**	**2.01**	**.048**
BIS-A	0.92	1.25	0.10	0.74	.464
BIS-M	−3.07	1.82	−0.24	−1.68	.097
BIS-N	0.17	1.45	0.02	0.12	.905
STAI-T	**−2.78**	**1.06**	**−0.34**	**−2.63**	**.010**
NUM	−0.38	0.35	−0.13	−1.09	.281
k	−0.05	0.04	−0.15	−1.29	.200

Notes: Overall $F(8,75) = 2.81$, $MSE = 18$, $p = .009$, $R^2 = .23$. With STAI-S in place of STAI-T in model: **STAI-S** $\boldsymbol{B = -3.01}$, $\boldsymbol{SE = 0.92}$, $\boldsymbol{\beta = -0.42}$, $\boldsymbol{t = -3.28}$, $\boldsymbol{p = .002}$. When adding all interactions with COND, only COND × BIS-A ($p = .069$) and COND × STAI-T ($p = .094$) approached statistical significance. Same pattern emerges with exclusion of *k* from predictors.

range = −5.54 - 26.39) and future-reward trials ($M = 7.17$ μV, $SD = 5.07$, range = −6.22-21.43; $t(83) = 1.43$, $p = .156$), the correlation between P3 activity for immediate- and future-reward responses was high ($r = .89$; $p < .001$), and correlations with other measures were similar across response types. For these reasons, P3 amplitudes were collapsed over response type for regression analyses.[3] A linear regression, as shown in Table 5, was conducted to test the relationship between condition (and individual difference variables) and P3 activity. The analysis identifies condition, gender, and trait anxiety (or state anxiety if included instead; these were considered separately because they are highly correlated) as reliable predictors of P3 amplitude. As predicted, individuals in the Gratitude condition had higher P3 amplitude than those in the Neutral condition (illustrated more fully in Fig. 2); and individuals with greater trait and state anxiety had lower P3 activity. No other measures or two-way interactions with condition were reliable predictors of P3. Notably, neither *k* nor numeracy (which was correlated with *k*) was correlated with P3. Given that numeracy was found to be greater in the Gratitude condition than in the Neutral condition (and thus the variables are correlated), we re-ran the regression after removing condition as a predictor. The effect of numeracy on P3 was unchanged, suggesting that the gratitude effect on P3 was not due to differences in numeracy between the two conditions. In sum, as predicted, gratitude condition influenced P3 amplitude but, surprisingly, P3 amplitude was not related to choice behavior overall. That is, individuals with greater P3 were not more likely to choose the future-reward choice option.

3.6. Discussion

3.6.1. Summary of findings

The present study builds on past behavioral work in which individuals showed less temporal discounting after being induced to experience gratitude relative to being in a neutral mood induction condition (DeSteno et al., 2014). Here, we similarly manipulated gratitude; however, unlike past work, we found no behavioral difference in discounting between conditions. We also found no relationship between trait anxiety or impulsivity and discounting behavior, but did find that discounting behavior was related to state anxiety and numeracy. Specifically, individuals with higher state anxiety and, independently, low numeracy had the highest rates of discounting. When we obtained ERP data for the P3, a measure of motivated processing of the stimulus, we found that, as predicted, individuals in the Gratitude condition had higher P3s than those in the Neutral condition. State and trait anxiety were also associated with P3 activity, with more anxious individuals having lower P3s; other individual difference measures (including rate of discounting) did not predict P3.

3.6.2. Behavioral findings

The non-replication of the behavioral gratitude effect here was unforeseen. One possible explanation for the non-replication is that because the difference in self-reported gratitude between conditions was smaller here than in DeSteno et al. (2014), the manipulation might have been insufficient for revealing an effect. Another possibility is that even though the task methods used here have been used in various past studies, one or more methodological decisions might have led to conditions under which the behavioral gratitude effect does not emerge. Differences here relative to DeSteno et al., 2014; largely resulting from adaptation of the task to the ERP context) include using hypothetical rather than real rewards, varying one choice option rather than both options, and having decision-task instructions precede the mood manipulation. It may be, for example, that in the context of a real reward, participant evaluations of experimenter trustworthiness to dispense the reward (which might vary with gratitude level) are more consequential. Or, possibly, administering practice discounting trials before the writing task set in motion a pattern of behavior such that the decision maker was later less sensitive to changes in affective state. These possibilities inform considerations for future behavioral and neurophysiological work in this area.

The above-described methodological choices could help to understand differences between the present study and some past findings involving trait anxiety and impulsivity. However, it is likely that any negative relationship between each of these measures and discounting is weak, at most, with non-clinical student samples. While our own behavioral findings with trait anxiety were not statistically significant, the correlations were suggestive (e.g., $r = .19$ for trait anxiety and discounting) and similar in pattern to state anxiety, suggesting a possible weak relationship, or perhaps one that might have even been obscured by a modest presence of state anxiety in response to the ERP context. With regard to trait impulsivity, there was no evidence of a reliable relationship with discounting behavior. The latter is not surprising given the large body of studies with mixed findings that has led many to recently conclude that impulsive choice (i.e., discounting behavior), impulsive action, and impulsivity scales largely measure different types of impulsivity (see MacKillop et al., 2016).

The finding here that more numerate individuals had lower rates of discounting is consistent with findings from several past studies that used only a few discounting questions and thus could not calculate discount rates, but did find that more numerate individuals were more likely to choose the future rewards (Ghazal et al., 2014; Peters et al., 2008). The present finding also supports the broader conclusion that

[3] The analyses were also run with response type treated as a within-subjects variable, and there are no interactions between response type and gratitude condition.

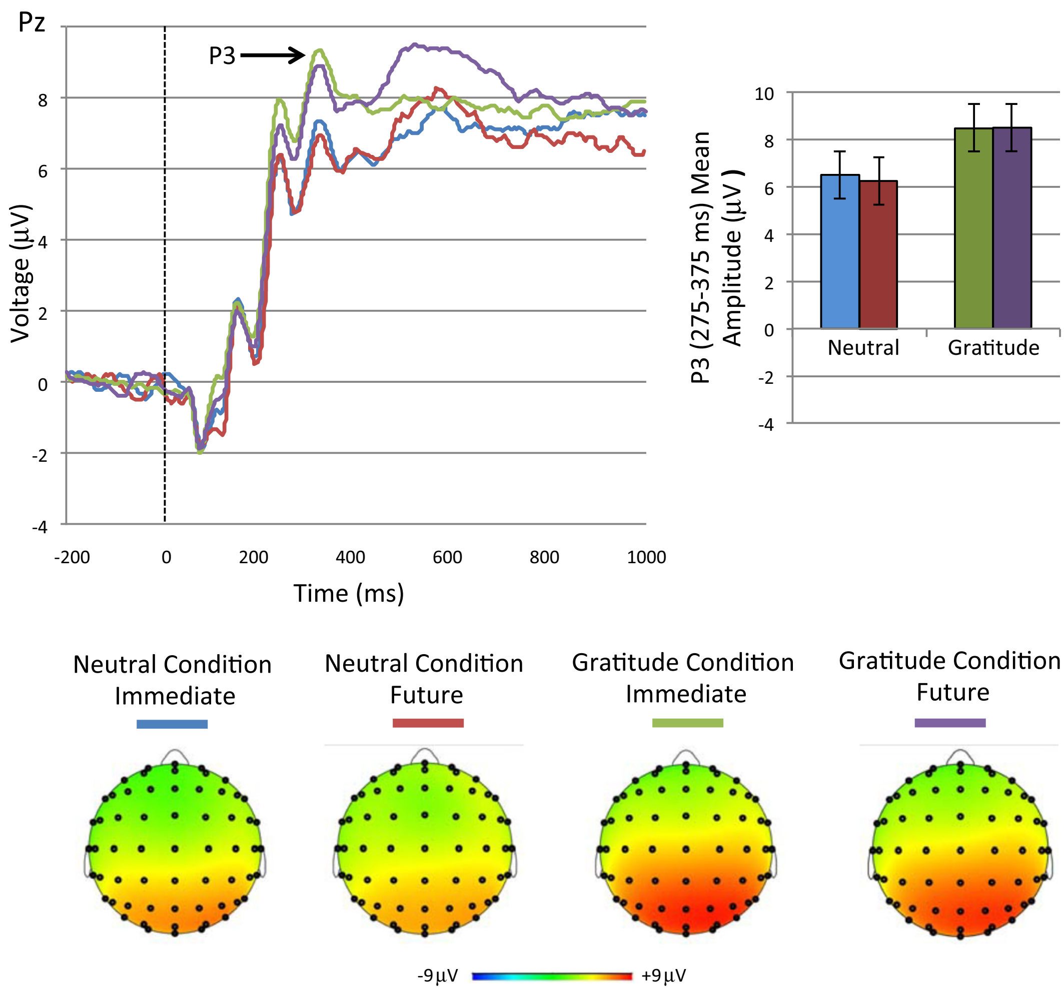

Fig. 2. (a) Stimulus-locked activity at electrode Pz by condition (Neutral vs. Gratitude) and response type (Immediate vs. Future), (b) P3 mean amplitude in 275–375 ms time window after stimulus presentation, and (c) voltage maps for the same time window.

more numerate individuals pay more attention to numerical information and use it more precisely in decision making (see Reyna et al., 2009, for review). What is perhaps most striking in the behavioral data here is that numeracy predicted more of the variation in discounting rate than any other measure. This suggests that numeracy might be as important as affect-related measures, at least within a college population, for understanding discounting, and might be a route to reducing present-focused bias. That said, we found no evidence of an interaction between numeracy and state anxiety, and thus it seems unlikely that numeracy training would be likely to mitigate any effects of anxiety on discounting behavior.

3.6.3. ERP findings

Although there was no influence of gratitude manipulation on discounting behavior, individuals in the Gratitude condition had higher P3 amplitude, as predicted. We proposed a gratitude effect on P3 on the grounds that affective states are generally believed to impact the motivational value of choice stimuli by influencing content of thought, depth of thought, and primary goals during decision making (see Lerner et al., 2015, for review). Emotions with positive valence such as gratitude have been associated with broader attention and more flexible processing (e.g., Pyone and Isen, 2011; see Isen, 2001, for review), and gratitude has specifically been associated with greater consideration of long-term benefits of choices. In contrast, anxiety signals threat and has been associated with a narrowing of attentional focus, vigilance, avoidance of risk, a tendency to interpret ambiguous situations in a negative light, and a goal of trying to improve one's immediate state (see Hartley and Phelps, 2012, for review). One interpretation of the P3 finding here is that gratitude and state anxiety differentially affect the extent to which future-reward choices are engaged for further processing. Individuals induced to experience gratitude might more readily engage with the future-reward stimulus (e.g., evaluate the dollar value in relation to the time delay), even on trials where these individuals ultimately choose the immediate reward. In other words, the simple prospect of waiting for a higher future-reward option might be more compelling for individuals in the Gratitude condition, thereby leading to more in-depth processing of this stimulus type.

While we find this interpretation compelling in the context of past work, it does not fully fit with other findings from the present study. We predicted that individuals with greater orientation towards delayed rewards (as reflected in greater P3) would be more likely to choose these rewards relative to other individuals. However, this was not the case here: the Gratitude condition influenced P3 but not rate of discounting, while numeracy predicted rate of discounting but not P3 (and, more generally, rate of discounting itself was not correlated with P3). One possible resolution of the discrepancy is that openness towards a future-reward option and final valuation of that option need not correspond as closely as initially predicted. The P3 might reflect the more grateful individuals' initial openness towards a delayed option or initial engagement with the larger dollar value for this option. But it need not reflect the final valuation of the future-reward option that arises from integration of reward value with delay amount, nor comparison of this value with that of the immediate-reward choice. It is possible that more grateful individuals in the present study had the predicted heightened response to the future-reward option as a result of enhanced interest in the larger delayed reward, but this enhancement was insufficient in the present context to result in a change in behavior.

An alternative and more parsimonious account of the findings in the present study comes from the fact that the P3, in addition to being associated with motivated stimulus processing, has also been associated with general state of arousal or more focused attention on a task (see Polich and Kok, 1995, for review). In the present study, greater P3 amplitude in the Gratitude condition could have resulted from greater allocation of attentional resources to the task overall, rather than from a change in sensitivity to the future-reward choice option driven by gratitude-related motivations. Similarly, a lower P3 among more anxious individuals might have resulted from overall lower allocation of attentional resources to the choice task, perhaps due to distraction associated with the ERP procedure. Such an account would explain why P3 activity was not related to choice behavior, and why correlates of P3 activity and those of discounting behavior were distinct. Because we did not separately measure response to an immediate-reward choice versus response to a future-reward choice, we cannot tease apart explanations of findings that assume enhanced future-reward evaluation versus those that assume enhanced task processing more generally. Even though both the Gratitude and the Neutral writing tasks involved a focused writing activity, writing about a single experience of gratitude might have served to focus attention, similar to mindfulness activities that have been shown to enhance focused attention (e.g., Dickenson et al., 2013; Jha et al., 2007).

The P3 finding is important here in that it provides first evidence of change in ERP activity in response to a short gratitude manipulation. The study also raises questions for future research regarding interpretation of the P3 elicited by subjective choice stimuli. In the present work, we considered that the P3 might be associated with stimulus components that engage the individual, or that it might reflect overall level of attention to the task. In some studies, the P3 has also been found to be greater when one makes his or her generally preferred choice (e.g., Xia et al., 2017), and thus is associated with response preference. And, in one study using a different methodology than the present one, in which P3s were larger for individuals who preferred the immediate-reward option, P3 amplitude was interpreted as reflecting a negative response to uncertainty associated with the delayed reward (Li et al., 2012). The findings collectively suggest that the P3 may be sensitive to a wide variety of elements of subjective decision making tasks, and that further work is needed on correlates of the P3 in this domain.

3.6.4. Conclusions

There is growing interest in the neural processes of gratitude, the relationship between gratitude and behavior, and ways by which gratitude interventions might promote overall health and well-being. The present study extends existing behavioral research by illustrating changes in brain electrophysiological activity associated with the experience of gratitude during the contemplation of choices with immediate versus future consequences. There are a number of important directions for future research that stem from the present work including: elaboration of how more versus less grateful individuals mentally represent choice alternatives during temporal discounting; the assessment of whether gratitude-induced P3 activity generalizes to other types of choice options previously associated with gratitude (i.e., options that benefit the greater good) as well as to stimuli in P3 tasks (e.g., oddball task) less obviously related to gratitude; and the development of studies aimed at furthering our understanding if and how choice strategy, P3 activity, and discounting behavior are related to one another.

Conflicts of interest

None.

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