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Motivational processes from expectancy-value theory are associated with variability in the error positivity in young children

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Abstract

Motivational beliefs and values influence how children approach challenging activities. The present study explores motivational processes from an expectancy-value theory framework by studying children's mistakes and their responses to them by focusing on two ERP components, the error-related negativity (ERN) and error positivity (Pe). Motivation was assessed using a child-friendly challenge puzzle task and a brief interview measure prior to ERP testing. Data from 50 four- to six-year-old children revealed that greater perceived competence beliefs were related to a larger Pe, while stronger intrinsic task value beliefs were associated with a smaller Pe. Motivation was unrelated to the ERN. Individual differences in early motivational processes may reflect electrophysiological activity related to conscious error awareness.

Keywords

Motivation; error-related negativity; error positivity; children

Introduction

Motivational processes and children's mistakes

Motivation is a set of beliefs, values, and emotions that influence how an individual tackles an activity or goal (Pintrich & Schunk, 2002). Motivational processes may be particularly activated during challenging situations in which making mistakes and experiencing temporary setbacks are not uncommon. In the face of difficulty, children can either be persistent and oriented towards mastering the activity, or can give up and exhibit feelings and behaviors associated with helplessness (Smiley & Dweck, 1994). Understanding how

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individuals respond to mistakes as they work towards achieving a goal can help to reveal the nature of motivation in young children. Is a mistake a learning opportunity that can help a person to achieve better outcomes in the future? Or is it a cause for concern, prompting the person to question her ability and thereby altering her expectations? The aim of the present study was to explore the nature of children's mistakes and their responses to errors in order to better understand early motivational processes. Specifically, we used the event-related potential (ERP) technique to explore specific patterns of brain responses associated with error processing that may provide valuable new insights into the nature of motivation in young children.

The expectancy-value (E-V) theory of motivation proposes that achievement can be explained by an individual's beliefs about how well she will do on an activity as well as the extent to which she values or enjoys the activity (e.g., Wigfield, Eccles, Schiefele, Roeser, & Davis-Kean, 2006). Expectancy refers to an individual's perceived ability as well as one's expectations for success. Children's beliefs about their future expectations of success and their current competencies load onto the same factor (Eccles & Wigfield, 1995), suggesting that expectancy may be a unitary construct in early childhood. The majority of empirical work testing E-V theory conceptualizes value as a multidimensional construct that includes attainment value (importance of a task), utility value (usefulness of a task), and intrinsic value (enjoyment); for young children, the intrinsic value or enjoyment of an activity is arguably the most salient feature of value (Wigfield & Eccles, 2000). While these motivational orientations have traditionally been associated with achievement, we propose that achievement-related beliefs and values that an individual possesses may be associated with how individuals think about and respond to their mistakes. That is, these different motivational orientations may have neural correlates in addition to behavioral response patterns. ERP studies of human error processing have yielded important insights into how individuals respond to their mistakes, and can therefore provide a unique perspective in our understanding of complex motivational processes.

Motivation and the error-related negativity (ERN)

One ERP component of potential interest is the error-related negativity (ERN), which is thought to be generated by the anterior cingulate cortex and is seen as a negative-going deflection occurring about 50 milliseconds following an incorrect response on a speeded target discrimination task (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Coles, Meyer, & Donchin, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993; see Gehring, Liu, Orr, & Carp, 2012, for a review). The ERN is present in children as young as three years of age (Grammer, Carrasco, Gehring, & Morrison, 2014) and may be sensitive to development (e.g., Davies, Segalowitz, & Gavin, 2004; DuPuis et al., 2015). Several lines of evidence suggest that the ERN is related to motivation, although different theories of the ERN explain these effects through different mechanisms. The different ways in which motivation has been conceptualized reflects the classic person-situation debate as to whether the person or the situation is more influential in determining achievement. Whereas motivation has traditionally been regarded as a trait-like characteristic in educational and personality psychology, motivation has more often been conceptualized as situation-based in ERP research. The ERN, for example, is larger in conditions that emphasize accuracy over speed (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring et al., 1993). A prominent theory of the ERN, conflict-monitoring theory, accounts for the motivational influences in this case via the effects of increased focal attention when accuracy is emphasized (Yeung, Botvinick, & Cohen, 2004). An alternative perspective, reinforcement learning theory (Holroyd & Coles, 2002), proposes that the ERN is generated when the consequences of an action are worse than expected, emphasizing the loss of value and unexpectedness of an error. Related to this, the ERN is thought to reflect the distress associated with the violation of expectancy caused by the error (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003), although recent research suggests that it may be more sensitive to error significance rather than error expectancy (Maier & Steinhauser, 2016). The ERN is also sensitive to different aspects of value. The component is larger when monetary penalties for errors are increased compared to low-penalty (or low value) trials (Hajcak, Moser, Yeung, & Simons, 2005), and it may also be affected by the degree to which an individual cares about doing well on an activity (Segalowitz & Dywan, 2009). From an E-V perspective, caring about doing well may reflect the value or importance one places on high performance.

Motivation and the error positivity (Pe)

A related ERP component, the error positivity (Pe), may also provide valuable insights into motivational processes. Various hypotheses have been offered regarding the functional significance of the Pe. Particularly relevant to the current study is the error awareness hypothesis, which proposes that the Pe reflects processes underlying the participant's conscious awareness and recognition of the error, as well as the increased attention to the mistake (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). We propose that motivational characteristics may be more closely related to cognitive processes associated with the awareness of one's responses as indexed by the Pe, permitting more concrete predictions regarding the relation between motivation and the Pe compared to the ERN. The Pe accompanies the ERN and is observed at centroparietal electrode sites, occurring about 200 to 500 ms after an incorrect response (Gehring et al., 2012). It is also present in young children and shares a spatial and temporal distribution similar to that of older children and adults (Grammer et al., 2014; Torpey, Hajcak, Kim, Kujawa, & Klein, 2012).

Because the ERN can be observed even when individuals are unaware that a mistake has been made (Endrass, Reuter, & Kathmann, 2007; Nieuwenhuis et al., 2001), it may index an automatic process of error detection that is less sensitive to trait-like motivational processes compared to the Pe. Recent work provides support for this general hypothesis. Research on perfectionism suggests that higher levels of concern over mistakes are related to a larger Pe but not to the ERN (Tops, Koole, & Wijers, 2013). A related study showed that holding higher standards or expectations for performance was related to a larger Pe (Stahl, Acharki, Kresimon, Voller, & Gibbons, 2015). Individuals with a growth ability mindset (associated with persistence and motivation to succeed) exhibit an enhanced effect of errors on the Pe compared to individuals with a fixed ability mindset (associated with helplessness and reduced effort), but no associations with the ERN (Moser, Schroder, Heeter, Moran, & Lee, 2011). Extending this logic to E-V theory, we might expect that individuals who believe they are good at an activity (or expect to succeed) to show enhanced attention to corrective feedback, so that they can use the feedback information to make appropriate adjustments in order to meet their expectations about their strong ability; this error awareness may be reflected in a larger Pe. While there has been less research exploring value and the Pe, one study examining this link in adults demonstrated that ratings of the subjective importance of an academic exam—similar to utility value or usefulness conceptualized in E-V theory—were positively related to the Pe, but not to the ERN (Wu et al., 2014). We might also expect to find a similar association between value and the Pe in children.

Aims and hypotheses

The present study had two primary aims. First, given the relative paucity of research on ERPs in young children, we attempted to replicate recent findings (e.g., Grammer et al., 2014) that the ERN and Pe can be observed and measured in four- to six-year-old children. Second, we explored the nature of motivation in young children and whether individual differences in young children's motivation were related to neural measures of error processing. We also sought to reconcile the apparent contradiction that the ERN is related to expectancy and value with the body of empirical work suggesting that motivational processes are more closely related to the Pe rather than the ERN. To that end, we tested whether there were distinct effects of motivation on the ERN and Pe, and if so, whether there were distinct effects across expectancy and value beliefs. Specifically, we predicted that children who express stronger beliefs about their high competence would pay more attention to their mistakes that are presumably unexpected given their stated beliefs, which would be reflected in a larger Pe. Deriving predictions regarding the value part of E-V theory was less straightforward. Children who expressed stronger intrinsic task value beliefs might pay greater attention to their mistakes because their enjoyment of the activity may be negatively affected by failure experiences; these children should exhibit a larger Pe. On the other hand, children who expressed stronger value beliefs might pay less attention to their mistakes because engaging in the activity is intrinsically rewarding and performing well is not a major concern, thereby exhibiting a smaller Pe. Both interpretations seem plausible and we left open the possibility that our data may support either prediction. Given the mixed evidence linking expectancy and the ERN, we did not make any specific predictions regarding this association. However, as described above, given evidence suggesting that different aspects of value are associated with the ERN, we predicted that greater intrinsic value would be associated with a larger (more negative) ERN.

Method

Participants

Sixty-five children (41 boys, 24 girls) between four and six years of age (*M* = 5.30 years, *SD* = 0.86) participated in this investigation. Participants were recruited through a variety of methods, including presentations at area preschools, posting of flyers in universities and childcare centers, and an online study recruitment database. The accompanying parent filled out a background questionnaire.

Of the initial sample of 65 children who participated in the study, 46 children generated usable full-case ERP data. Four children did not contribute complete ERP data due to technical errors or child refusal to complete all eight blocks of the Go/No-Go task (one child contributed three blocks, another contributed four blocks, and two children contributed seven blocks). However, because close inspection of the averaged correct and error waveforms for these children did not indicate any unusual distortions or artifacts, and because each child contributed at least six errors in the ERP averages, these four children were included in our final analysis sample of 50 children. Of the 15 children who were excluded from the analysis, eight children did not participate in the EEG portion of the assessment due to refusal, lack of cooperation, or ineligibility based on parent report of the child's health condition, five children were dropped from the analysis due to unusually poor data quality after visual inspection of the raw EEG data, and two children who committed fewer than six errors were dropped from the sample based on the criterion proposed by Pontifex and colleagues (Pontifex et al., 2010).

The demographic characteristics of our study sample reflected the communities from which our families and children were recruited. Of our analysis sample of 50 families and their children, 42 children (84%) were Caucasian; three children were Asian, two children were African American, and two children were American Indian/Alaska Native. One parent did not provide race/ethnicity information. Forty-six parents (92%) reported highest educational attainment of a college degree (or equivalent) or higher. Nine parents (18%) reported a total household income of less than $50,000. Parents reported on the child's health conditions using an open-ended question format; children were only included in the analysis if parents did not report any psychiatric, psychological, or neurological disorder.

Procedure

Testing took place in a child-friendly laboratory and was conducted by trained experimenters. Upon receiving verbal child assent, children completed a series of direct behavioral assessments that included measures of motivation. Children were given stickers at regular intervals to promote enthusiasm and engagement in the tasks, and were also given opportunities to take breaks in the adjoining waiting room/play area. In the adjoining room, the accompanying parent filled out a background questionnaire. The door to the testing room was kept open in order for the parent to be able to quietly supervise what was going on during testing. After the behavioral assessments, children participated in ERP testing.

Assessment of expectancy and value beliefs

Measurement of motivation in young children is particularly challenging, given the difficulty of designing assessments that reliably capture these constructs in early childhood. Despite these methodological challenges, researchers have been successful using a child-friendly puzzle activity paradigm by assessing children's reactions while solving increasingly challenging puzzles. In the present study, we used a challenge puzzle task designed to measure young children's achievement goal orientations, similar to the paradigm described in Smiley and Dweck (1994). This puzzle involves colored blocks of various shapes and sizes, and was selected to be similar to toys and games that children might be familiar with at their preschools and homes. Children were shown a card with a design and asked to arrange the blocks to match the design on the card. If the child successfully completed the first design in four minutes or less, a second, more challenging design was provided. The task continued until the child attempted a design that she was unable to successfully complete in four minutes.

We then administered the puppet interview, an eight-item measure adapted from the Puppet Interview Scales of Competence in and Enjoyment of Science (PISCES; Mantzicopoulos, Patrick, & Samarapungavan, 2008), that assessed a child's expectancy and value beliefs about the puzzle task that the child had just completed. Children were presented with puppets and were asked to choose the one that was most like them. Then, the puppets “spoke” to the child, with one puppet saying “I like doing puzzles like this one” and the other saying “I don't like puzzles like this one.” Then, the experimenter asked the child, “Which puppet thinks the same as you?” and directed her to point to the puppet that thought like her. Children responded to four dichotomous statements that captured perceived competence (Puzzles like this one are easy/hard, I know/don't know how to do puzzles, I can't/can do puzzles, I'm good/not so good at puzzles) and four dichotomous statements that captured intrinsic task value beliefs (I like/don't like doing puzzles like this one, I don't have/have fun doing puzzles, I want/don't want to know more about puzzles, I feel/don't feel happy when I am doing puzzles). Scores for each subscale ranged from zero to four; for example, a score of three on the perceived competence subscale would denote that the child selected three positively-valenced statements (or conversely, one negatively-valenced statement was selected). It is important to note that motivation and ERPs were not assessed concurrently in the present study.

Go/No-Go Task

Participants played a child-friendly Go/No-Go task called the Zoo Game, which has been successfully used with young children and has demonstrated to elicit an observable ERN and Pe (e.g., Grammer et al., 2014; He et al., 2010; Lamm, White, McDermott, & Fox, 2012; Lamm et al., 2014; McDermott, White, Degnan, Henderson, & Fox, under review). In the game, children were told that someone had let all the animals out of their cages, and that it is the child's job to help the zookeeper put all the animals back in their cages by pressing a button on a response device. The children were told that they would have three orangutan assistants who would help them catch the animals. Children were shown pictures of each of the three orangutans and were told to remember them and not to capture them because they are helping. Therefore, the No-Go stimuli were the three orangutans and the Go stimuli were all the other animals. Sample images from the Zoo Game are presented in Figure 1.

The Zoo Game was presented using E-Prime 2.0 (Psychology Software Tools, 2010) on a 22-inch Asus LCD monitor. Each trial started with the presentation of a fixation cross for 300 ms, then an image of an animal (the stimulus) for 750 ms, and a blank, black screen for 500 ms. The ratio of Go to No-Go trials was 3:1, with 30 Go animals and 10 No-Go orangutans presented in each of eight blocks. Children were given the opportunity to practice during a practice block consisting of 12 trials with the same ratio of Go to No-Go animals. Responses were registered during image presentation as well as during the blank screen. All images were of the same size and were selected carefully so that the animals were easily identifiable from the background but were not particularly salient for other reasons. This was done in order to prevent children from being drawn to a particular animal because of the image background or other peripheral features. Children made responses on a standard game controller (Logitech Dual Action Game Pad USB). Both speed and accuracy were emphasized; participants were instructed to catch the animals as fast as possible, with regular reminders not to press the button for the orangutan friends. In order to reduce anxiety and worry, children were reassured that if they accidentally put the orangutans in their cages, they could get free and help catch the other animals again. To sustain enthusiasm and task engagement, children were provided with short breaks as necessary.

Electrophysiological recording

EEG data were acquired using a BioSemi Active Two system using 32 Ag/AgCl electrode caps suitable for young children. A small amount of electrolyte (SignaGel) was applied to the child's scalp at each electrode. Flat electrodes were placed around each child's eye in order to account for vertical and horizontal eye movement artifacts. Electrode offsets were between ± 30 μv. Reference recordings were acquired by placing flat electrodes at each mastoid location (behind the left and right ears). Data were recorded referenced to a ground formed from a common mode sense (CMS) active electrode and driven right leg (DRL) passive electrode (see http://www.biosemi.com/faq/cms&drl.htm).

Offline, all data processing was performed using ERPLAB (Lopez-Calderon & Luck, 2014). EEG data were digitized at 512 Hz and were resampled at 256 Hz after recording. Prior to eye movement correction, data were screened using a programmed set of algorithms that rejected trials that met any of the following three criteria: (1) the absolute voltage range for any individual electrode exceeded 500 μV, (2) a change greater than 50 μV was measured between two consecutive data points, and (3) the data deviated by more than +25 or -100 dB in a frequency window of 20-40 Hz in order to detect and remove muscle artifacts. From the continuous EEG, 1,000 millisecond segments were extracted beginning 400 ms prior to correct and erroneous responses. ERP data were corrected for blinks and eye-movement artifacts using the method developed by Gratton, Coles, & Donchin (1983). Examination of the grand-averaged waveforms indicated that a baseline correction of 300 to 200 ms before the response would properly adjust for any brain activity occurring before stimulus presentation. Each trial was then visually examined for artifacts and rejected if muscle or other artifacts were still present after the automated artifact correction procedure. In the following figures, waveforms were filtered with a nine-point Chebyshev II low-pass, zero-phase-shift digital filter (Matlab R2010a; Mathworks, Natick, MA), with a half-amplitude cutoff at approximately 30 Hz.

The ERN was defined as the mean voltage in the window from -50 to 50 ms (0 ms denoting the response). (Negative ERN amplitudes were interpreted as negative polarities; that is, a larger ERN indicates a more negative ERN, and a smaller ERN indicates a less negative ERN.) The Pe was defined as the mean voltage in the window from 200 to 500 ms. Both the ERN and Pe were compared to correct trial activity in the same windows. Difference scores were also calculated in order to remove the brain activity occurring during both correct and incorrect responses, thereby producing a measure of activity specific to errors (e.g., Torpey et al., 2012). Statistical analyses were conducted using Stata 13.1.

Results

Attrition analysis

Independent group t-tests showed that there were no significant differences between children who were included in the analysis and children who were excluded on age, gender, parent educational attainment, response accuracy during the Zoo Game, and reaction time on correct and error trials. However, children living in households with incomes of less than $50,000 were more likely to be excluded from the analysis, $t(63) = 2.32$, $p = .02$.

Expectancy and value in young children

Consistent with previous research showing that young children are optimistic about their abilities (Eccles, Wigfield, Harold, & Blumenfeld, 1993; Nicholls, 1979; Stipek & Greene, 2001), we found that children's beliefs about their perceived competence (expectancy) on the puzzle task and their beliefs about liking and enjoying (value) the puzzle activity were high. For the perceived competence subscale ($M = 3.32$, $SD = .71$, Range: 2-4), 43 children (86 percent) scored three or four out of four positive statements. For the intrinsic task value subscale ($M = 3.56$, $SD = .61$, Range: 2-4), 47 children (94 percent) scored three or four out of four positive statements. Our data indicated that there were very few children who scored two or lower on either motivation subscale. However, because all children in our analysis sample demonstrated an understanding of the motivation task, these data points are better understood as accurate reflections of the child's self-reported motivation rather than as outliers. Despite the limited variability, we retained the continuous nature of these motivation variables in order to explore whether small differences in young children's expectancy and value beliefs were related to meaningful ERP differences. Perceived competence and intrinsic task value were not related to each other, $r_s = .10$, $p = .48$. Moreover, expectancy ($r_s = .04$, $p = .76$) and value ($r_s = -.08$, $p = .55$); were not significantly correlated with child age; it is possible that age-related change in motivation is not observable in our narrow age range of four to six years.

Go/No-Go task performance

Children's accuracy and reaction time on correct (Go) and error (No-Go) trials are presented in Table 1. Consistent with previous research, children were slower in responding on correct trials compared to error trials; this difference was statistically significant, $t(1,49) = 13.60$, $p < .001$. Child age was positively associated with accuracy on Go trials ($r = .27$, $p = .06$) but not with error rate on No-Go trials ($r = .09$, $p = .54$). Older children exhibited quicker reaction times on both correct trials ($r = -.42$, $p < .01$) and error trials ($r = -.25$, $p = .08$). Perceived competence beliefs and intrinsic task value were not related to any of the accuracy and reaction time measures.

ERP measures

ERN—Waveforms for response-locked ERPs for error and correct trials are shown in Figure 2 at midline electrode sites. The ERN was observed as a negative deflection peaking in a window between 50 ms before the response and 50 ms after the response at frontocentral electrode sites. In order to test for the presence of an ERN, we conducted a 3 (Electrode Site: FCz, Cz, Pz) × 2 (Trial Type: Correct, Error) repeated measures ANOVA. We found a significant main effect of electrode site, $F(2,49) = 127.36$, $p < .001$, $\eta_p^2 = .51$, $\varepsilon = .64$, indicating that frontocentral sites were associated with a greater negativity. We also found a significant main effect of trial type, $F(1,49) = 24.70$, $p < .001$, $\eta_p^2 = .09$, indicating that error trials were also associated with a greater negativity compared to correct responses. Importantly, the significant interaction between electrode site and trial type indicates that the amplitude difference between correct and error trials varied as a function of electrode site, $F(2,49) = 33.90$, $p < .001$, $\varepsilon = .61$. Follow up post-hoc paired sample t-tests demonstrated that amplitudes at FCz, Cz, and Pz were more negative on error trials compared to correct responses (*ps* < .001). The ERN was larger at FCz compared to Cz, $t(49) = -8.28$, $p < .001$, suggesting that the ERN was maximal at FCz. Consistent with previous work using the same Go/No-Go task in a similar age range (Grammer et al., 2014), the mean difference between the ERN and the correct response negativity, or CRN (i.e., ΔERN), was not significantly different between FCz and Cz, $t(49) = 1.15$, $p = .26$. Scalp topography maps of the ΔERN are presented in the Appendix.

Pe—The Pe was observed as a slow positive deflection between 200 and 500 ms after the response at centroparietal electrode sites. In order to test for the presence of a Pe, we conducted a 3 (Electrode Type: FCz, Cz, Pz) × 2 (Trial Type: Correct, Error) repeated measures ANOVA. We did not find a significant main effect of electrode site, $F(2,49) = 2.26$, $p = .11$, $\eta_p^2 = .02$, $\varepsilon = .94$, indicating that centroparietal sites were not associated with a greater positivity. However, we found a significant main effect of trial type, $F(1,49) = 59.90$, $p < .001$, $\eta_p^2 = .20$, indicating that error trials were associated with a greater positivity compared to correct responses. Importantly, the significant interaction between electrode site and trial type indicates that the amplitude difference between correct and error trials varied as a function of electrode site, $F(2,49) = 46.23$, $p < .001$, $\varepsilon = .69$. Follow up post-hoc paired sample t-tests demonstrated that amplitudes at Cz and Pz were more positive on error trials compared to correct responses (*ps* < .001). The Pe was larger at Pz compared to Cz, $t(49) = -3.03$, $p < .01$, suggesting that the Pe was maximal at Pz. Moreover, the mean difference between the Pe and the correct positivity, or Pc (i.e., ΔPe), was significantly larger at Pz compared to Cz, $t(49) = -8.29$, $p < .001$, providing further evidence that the Pe was maximal at Pz. Mean amplitudes for ERP components at the midline electrode sites included in the ANOVAS are provided in Table 2. A correlation table presenting the relation between motivation variables and ERPs is provided in Table 3. Scalp topography maps of the ΔPe are presented in the Appendix.

Regression analysis: Associations between motivation and ERPs

In order to explore whether motivational processes of expectancy and value were related to the ERN and Pe, we implemented an OLS multiple regression model that included age, gender, and error rate as control variables. Because the amplitude means data in Table 2 as well as the ANOVAS both demonstrated that the ERN was largest at FCz and the Pe was largest at Pz, we focused our regression analysis at these sites. Kernel density estimates of the residuals in the dependent variables yielded normal distributions, satisfying the primary assumption underlying OLS that the errors are normally distributed. Regression estimates are presented in Table 4. Children's expectancy and value beliefs were not related to the ERN, as shown in columns 1 and 2. However, there was a significant effect of both expectancy and value on the magnitude of the Pe and the ΔPe at Pz, such that stronger perceived competence beliefs are related to a larger Pe, and stronger intrinsic task value beliefs are related to a smaller Pe. In other words, expectancy and value predict the magnitude of the Pe in opposite ways. Error rate was also negatively related to the magnitude of the ΔPe, such that worse accuracy on No-Go trials was related to a smaller ΔPe. Bivariate scatterplots depicting the relation between expectancy and value and the ΔPe are presented in Figure 3; stronger perceived competence beliefs are related to a larger ΔPe (left panel), while stronger intrinsic task value beliefs are related to a smaller ΔPe (right panel). Median split waveforms comparing high versus low expectancy and value beliefs are presented in Figure 4.

One potential critique is that because there were so few children at the lower end of intrinsic task value distribution, our effects might be driven by these children. To explore this possibility, we conducted a sensitivity test by excluding the three children with a score of less than three on the intrinsic task value subscale and generating new OLS estimates. Not surprisingly, the standard errors associated with our estimates increased due to the decreased variability in our motivation variables. Even so, we found that the effects of perceived competence on the Pe and ΔPe remained significant. Our intrinsic task value results were more sensitive to the exclusion of these children; the effect of intrinsic task value on the magnitude of the ΔPe was no longer significant, but the effect remained when examining the Pe. Regression estimates for this sensitivity test are presented in the Appendix.

Discussion

The present study explored how individual differences in young children's motivational characteristics were associated with electrophysiological patterns related to errors. Children's motivational beliefs and values from expectancy-value theory were related to the Pe but not to the ERN. Specifically, children's perceived competence beliefs were positively related to the Pe, while intrinsic task value beliefs were negatively related to the Pe.

ERN and Pe

Our first aim was to replicate recent findings that the ERN and Pe can be observed and measured in four- to six-year-old children; this was indeed the case. One important feature of the ERN in our sample of young children is that the error-correct difference that defines the ERN seems to begin before the zero millisecond mark (before the response is registered). Young children may have already cognitively initiated the incorrect response—which is correctly being indexed by the ERN—as the downward movement of the button press has yet to be registered by the acquisition system. This suggests that there is an important dissociation between error awareness and motor responses in young children. This is consistent with research demonstrating that there are no significant differences in ERN latency between children and adults when latency is time-locked to EMG onset rather than button press (e.g., Kim, Iwaki, Imashioya, Uno, & Fujita, 2007).

Relating motivation and the ERN and Pe

Our second aim was to explore the nature of motivation in young children and whether individual differences in young children's motivation were related to neural measures of error processing. We found that children's motivational characteristics were related to the Pe but not to the ERN. Recall that the Pe is thought to reflect response monitoring processes that include the conscious awareness of and the increased attention to the mistake (Nieuwenhuis et al., 2001; Overbeek et al., 2005). These processes seem to be related not to automatic error detection as indexed by the ERN (e.g., Gehring et al., 2012), but rather to motivational processes—such as holding and expressing personal beliefs about achievement —associated with a higher-order appraisal of the response and its implications. Our findings add to the growing literature (e.g., Moser et al., 2011; Schroder, Moran, Donnellan, & Moser, 2014) demonstrating that the Pe reflects achievement-related motivational processes.

The variability in our perceived competence and intrinsic task value measures was limited; the range of scores on each measure was between two and four (out of four), with no child scoring a zero or one on either measure, underscoring some of the methodological challenges associated with measuring motivational processes in young children discussed earlier. However, despite the limited variability within each measure, it is important to note that we still found that each set of beliefs was significantly related to the magnitude of the Pe. This suggests that in young children, even small differences in perceived competence and intrinsic task value beliefs are related to meaningful variability in the Pe. However, as previously noted, our intrinsic task value effects were more sensitive to the exclusion of children at the lower end of the value distribution compared to our perceived competence effects. More data on children's expectancy and value beliefs are needed to determine whether our results are replicable and therefore generalizable to a broader child population. Finally, it is not problematic to use OLS regression even when the independent variables are not normally distributed; the primary assumption that the residuals are normally distributed was satisfied in our data.

Expectancy beliefs (perceived competence) and the Pe

Strong beliefs about one's perceived competence were associated with a larger Pe. Children who exhibit strong beliefs about their high ability may be more attentive to their mistakes. These children may have begun to assimilate a belief of “I am good at puzzles” into their developing sense of self and may therefore allocate increased attention to their mistakes in order to learn from them so that they can perform at a level that matches their beliefs. This is consistent with views suggesting that the Pe is related to the salience of the error (Endrass, Klawohn, Preuss, & Kathmann, 2012). Children with strong beliefs about their perceived competence may not only attend more closely to their mistakes, but the same mistake might be more apparent to a child with high expectations compared with a child who does not expect to perform well on the task.

Value beliefs (intrinsic task value) and the Pe

The Pe effect that we observed reflected a measure of value (i.e., liking and enjoyment) that is more salient and understandable to younger children, rather than utilitarian or monetary notions of value. Specifically, we conceptualized value as children's level of enjoyment on a puzzle activity and related that to neutral animal images in the Zoo Game. We found that children who expressed strong intrinsic task value beliefs had a smaller Pe. Children who enjoy and like an activity may be much less sensitive to their mistakes—or assign less meaning or importance to them—on another challenging activity. For these children, the intrinsic enjoyment that they derive from doing puzzles matters more than their actual performance and may therefore pay less attention to their mistakes, as errors do not interfere with their enjoyment of the activity. Our results present an alternative way to conceptualize value in terms of trait-like motivational processes that is still sensitive to variability in the Pe.

As described above, utility value measured in adults was related to a larger Pe (Wu et al., 2014). In that study, adults who placed greater emphasis on the results of an important exam, as well as those who exhibited higher perceived stress associated with the exam, exhibited a larger Pe. How can we reconcile these results with our finding that intrinsic task value is related to a smaller Pe? In addition to the error awareness hypothesis described above, another hypothesis of the Pe is that it reflects a subjective process related to the affective response to an error (e.g., Van Veen & Carter, 2002). Stress and enjoyment are very different emotional states and are likely to be related to different underlying affective processes. Taken together, these findings confirm the prediction of E-V theory that value is properly understood as a multidimensional construct, and exploring this complex link between value and the Pe would be a fruitful topic for future research.

Limitations and directions for future research

One of the primary limitations of the study is that we assessed children's motivational beliefs on a challenge puzzle activity and then related those beliefs to the ERP components that were generated from a different activity—the Go/No-Go Zoo Game. Given our data, we were unable to determine whether children's beliefs were consistent across both activities, but there are reasons to believe that they might be very similar. Research suggests that elementary-aged children have distinct beliefs about what they are good at and what they value in different achievement domains (Wigfield & Eccles, 2000). However, children without any formal schooling and who are relatively new to the formal school environment —such as the preschool, kindergarten, and first-grade children in our sample—may hold more domain-general beliefs about their perceived competence and intrinsic task value across different activities. Because of this, it is likely that children's beliefs would have been consistent across both the challenge puzzle activity as well as the Zoo Game. Nevertheless, future research should assess children's task-specific motivational beliefs—including the Go/No-Go task—in order to explore whether these expectancy and value beliefs are domain-general or domain-specific in this age range. Also, because of the important transition to formal schooling that occurs during this time, it would be important to understand whether schooling experiences might mediate the relation we observed between motivation and neural correlates of error processing.

Finally, it is important to consider the challenge of melding different levels of analysis in exploring motivation and error monitoring processes, as we attempted to do in the current investigation. Mapping a higher-level construct such as motivation onto moment-by-moment attentional processes in a Go/No-Go task is a difficult endeavor, and our results may be open to a number of alternative and equally valid interpretations. While we focused on the E-V theory of motivation in the current study, other theoretical perspectives of motivation may provide additional insights into the link between motivation and error monitoring that can enhance our understanding of both of these important processes in early childhood. Future research will benefit not only from progress in characterizing the cognitive and affective processes that give rise to the Pe, but also further efforts to work out how higher-level theories of motivation such as E-V theory map onto lower-level cognitive and affective processes.

In summary, the present study replicates findings from recent research suggesting that electrophysiological phenomena related to error processing can be measured and observed in children as young as four years of age. Moreover, individual differences in young children's motivational beliefs and values are related to the Pe, but not to the ERN. Specifically, when exploring motivation from expectancy-value theory, stronger perceived competence beliefs were associated with a larger Pe, while stronger intrinsic task value beliefs were related to a smaller Pe. Exploring cognitive processes related to motivation such as metacognition may provide additional insights into how children's abilities to reason about their own thinking can affect how they respond to and interpret their mistakes.

Appendix

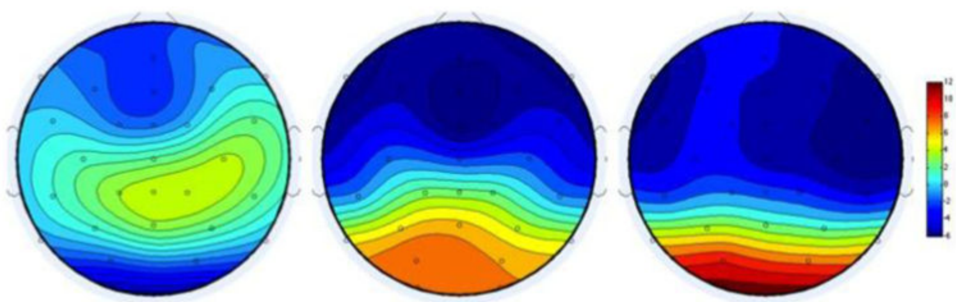

Figure A1.

Scalp distribution maps for the ERN. Left: CRN, Center: ERN, Right: ΔERN.

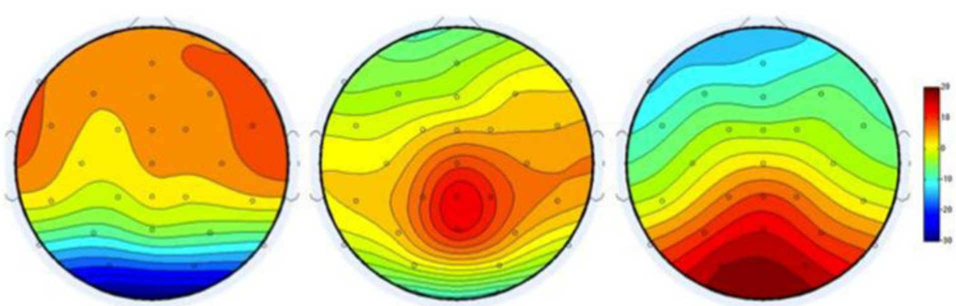

Figure A2.

Scalp distribution maps for the Pe. Left: Pc (correct positivity), Center: Pe (error positivity), Right: ΔPe.

Table A1

OLS regression estimates of age, gender, error rate, and expectancy and value on the ERN and Pe, excluding children scoring less than 3 on the intrinsic task value subscale

Variables Child age	(1) ERN (FCz)	(2) ΔERN (FCz)	(3) Pe (Pz)	(4) ΔPe (Pz)
Child age	-0.147 (0.812)	1.296 (0.952)	-1.704 * (0.990)	-0.341 (1.405)
Child gender[a]	0.458 (1.363)	2.186 (1.598)	-1.614 (1.661)	-1.941 (2.358)
Error rate (percent incorrect)[b]	-3.433 (4.241)	2.834 (4.973)	-2.093 (5.170)	-14.350 * (7.337)
Perceived competence beliefs (expectancy)	0.630 (0.916)	0.806 (1.074)	3.741 *** (1.117)	3.231 ** (1.585)
Intrinsic task value beliefs (value)	0.040 (1.382)	0.987 (1.621)	-3.638 ** (1.685)	-3.863 (2.391)
Observations	47	47	47	47
R-squared	0.037	0.111	0.300	0.229

Note. Standard errors are in parentheses.

*** p<0.001,

** p<0.01,

* p<0.05.

[a]Male = 0, Female = 1

[b]Expressed as a decimal between 0 and 1

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Highlights

- Links between motivation and neural indices of error monitoring were explored.
- The ERN and Pe were observed in children ages four through six.
- Perceived competence and intrinsic task value beliefs were differentially related to the Pe but not to the ERN.

Figure 1.
Sample images from the Go/No-Go Zoo Game.

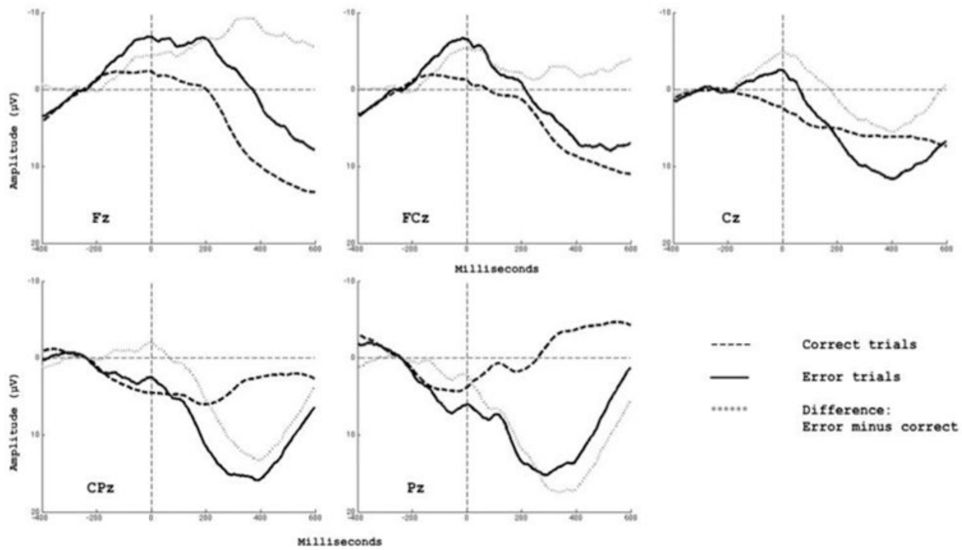

Figure 2.

Grand average waveforms at midline electrode sites. The vertical dashed line at time zero indicates the time of the response (button-press switch closure).

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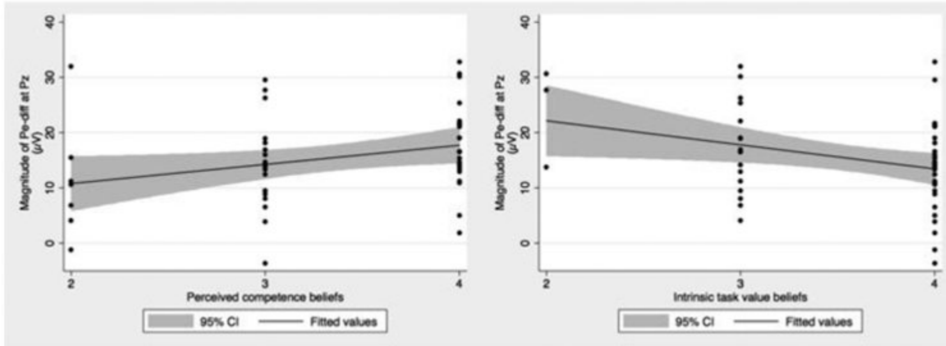

Figure 3.

Bivariate scatterplots of perceived competence beliefs (left) and intrinsic task value (right) on ΔPe at Pz.

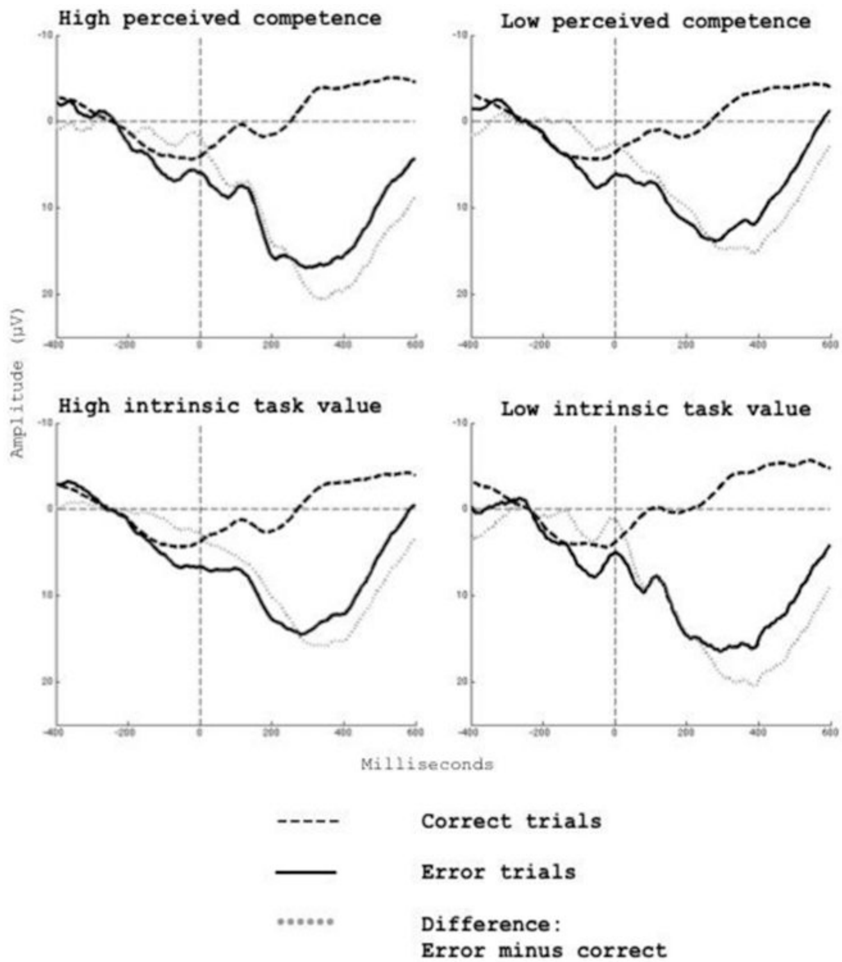

Figure 4.

Waveforms for children with high vs. low perceived competence beliefs (top) and intrinsic task value beliefs (bottom) at Pz. A median split was used to group children into high and low groups. The vertical dashed line at time zero indicates the time of the response (button-press switch closure).

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Table 1
Behavioral performance on the Zoo Game

Variables	Mean	SD	Range
Number of correct (Go) trials	203.60	34.90	72 - 239
Number of error (No-Go) trials	28.38	12.49	6 - 58
Percent correct (Go trials)	87.12	10.31	64.58 - 99.58
Percent incorrect (No-Go trials)	36.57	15.33	7.50 - 72.50
Reaction time (correct trials)	611.84	75.52	482.06 - 817.10
Reaction time (error trials)	497.68	63.68	360.94 - 613.95

Note. Reaction time is in milliseconds. Correct trials were defined as the number of correct responses on Go trials, excluding correct non-responses during No-Go trials. Error trials were defined as the number of errors of commission during No-Go trials, excluding errors of omission during Go trials.

Table 2

Mean amplitudes for ERP components at midline electrode sites

Components	FCz	Cz	Pz
ERN	-6.17 (4.28)	-1.94 (4.42)	6.60 (5.48)
CRN	-1.01 (3.47)	2.52 (3.31)	3.64 (4.55)
ΔERN	-5.16 (5.12)	-4.47 (4.59)	2.97 (5.84)
Pe	4.58 (10.02)	9.31 (9.14)	13.01 (6.00)
Pc	6.75 (6.52)	5.03 (6.03)	-2.34 (6.46)
ΔPe	-2.17 (9.13)	4.28 (8.51)	15.35 (8.39)

Note. Amplitude units are microvolts (μv). Standard deviations are in parentheses.

Table 3

Bivariate correlations between motivation variables and ERPs

Variables	PC	ITV	ERN (FCz)	ERN (Cz)	ERN (Pz)	ΔERN (FCz)	ΔERN (Cz)	ΔERN (Pz)
Perceived competence (PC)		.10	.03	-.03	.04	.02	-.09	.01
Intrinsic task value (ITV)	.10		-.09	-.27^{+}	.02	-.01	-.03	.08
	PC	**ITV**	**Pe (FCz)**	**Pe (Cz)**	**Pe (Pz)**	**ΔPe (FCz)**	**ΔPe (Cz)**	**ΔPe (Pz)**
Perceived competence (PC)		.10	.02	.06	.43**	-.10	.04	.34*
Intrinsic task value (ITV)	.10		-.22	-.37**	-.22	-.04	-.36**	-.25^{+}

Note. Values represent Spearman rhos.

**p<0.01,

*p<0.05,

$^{+}$p<0.10.

Table 4

OLS regression estimates of age, gender, error rate, and expectancy and value on the ERN and Pe

Variables	(1) ERN (FCz)	(2) ΔERN (FCz)	(3) Pe (Pz)	(4) ΔPe (Pz)
Child age	-0.167 (0.785)	1.300 (0.911)	-1.943* (0.952)	-0.092 (1.336)
Child gender[a]	0.501 (1.296)	2.103 (1.504)	-1.556 (1.573)	-0.996 (2.206)
Error rate (percent incorrect)[b]	-2.585 (4.087)	4.001 (4.743)	-4.239 (4.960)	-15.274* (6.957)
Perceived competence beliefs (expectancy)	0.657 (0.908)	0.830 (1.053)	3.590** (1.102)	3.462* (1.545)
Intrinsic task value beliefs (value)	-1.178 (1.041)	-0.018 (1.208)	-2.742* (1.264)	-4.744* (1.772)
Observations	50	50	50	50
R-squared	0.053	0.109	0.290	0.287

Note. Standard errors are in parentheses.

** $p<0.01$,

* $p<0.05$.

[a] Male = 0, Female = 1

[b] Expressed as a decimal between 0 and 1