NEURAL CORRELATES OF CHILDREN'S EMOTION UNDERSTANDING

ABSTRACT

This study aimed to develop an EEG paradigm to identify neural correlates of emotion understanding in children. In Experiment 1, children took part in an emotion story task. Results demonstrated larger LPP amplitudes for emotionally incongruent outcomes. In Experiment 2, children additionally completed a physical story task. Results replicated the results of study 1, and further demonstrated larger LPP amplitudes for both physical and emotional incongruent conditions. These latter findings may suggest the LPP is not a specific neural correlate of social-cognitive processing. However, post-hoc analyses showed that social or emotional features may have played a role in eliciting the LPP even in the physical stories. The study demonstrates the potential value of the LPP as a flexible probe for studying children's emotion understanding and encourages further work into the specificity versus generality of cognitive processes underpinning the LPP in social information processing.

INTRODUCTION

Emotion understanding (or affective mentalising) refers to the ability to accurately predict or understand a person's emotional response based on an understanding of the context that the person is in (e.g. Thompson, 1989). Clearly, emotion understanding is likely to depend upon emotion recognition, which has been subjected to extensive research (e.g. Collin, Bindra, Raju, Gillberg & Minnis, 2013; Harms, Martin & Wallace, 2010; Herba and Phillips, 2004; deHaan, Nelson, Gunnar & Tout, 1998; Gunnar & Nelson, 1994; Kestenbaum & Nelson, 1992). However, emotion recognition is just one element of the more complex ability to not just recognise emotions, but read behaviour and contexts in such a way that someone's emotional response can be predicted and understood. Emotion understanding is related to cognitive Theory of Mind, which refers to the ability to understand that other people have thoughts about a situation and that others' cognitions may be different to one's own (e.g. Baron-Cohen, 1991). This is typically measured with tests of false-belief, which require an understanding that it is possible for a person to hold a belief about a situation that is different from the reality of that situation. In addition, emotion understanding (or emotional Theory of Mind) involves knowing that others have inner emotional states that are triggered by different contexts and the meanings associated with them, and that emotions imply certain behavioural dispositions (e.g. Weimer, Sallquist & Bolnick, 2012).

Two models of emotional understanding have been proposed: a three developmental phase model (external, mental and reflective phases; Pons, Harris, & de Rosnay, 2004) and a two-factor structure (recognition of expressed emotion and understanding of context-dependent emotions; Bassett, Denham, Mincic, & Graling, 2012). Children are known to develop these different aspects of emotion understanding at different ages and individual differences in emotion understanding exist in early childhood (Pons et al., 2003). These remain significant in middle childhood, are relatively stable across time, and are seen across multiple facets of emotion processing (Pons & Harris, 2005). Deficits in emotion understanding have been linked to various markers of psychological distress, psychopathology (Southam-Gerow & Kendall, 2002), and poorer educational outcomes (Garner, 2010) in childhood. Impairments in emotion understanding abilities have also been demonstrated in a number of specific clinical populations, such as in children with Autism Spectrum Disorders (ASD; Golan, Baron-Cohen & Golan, 2008), Attention-Deficit Hyperactivity Disorder (ADHD; e.g. Da Fonseca, Seguier, Santos, Poinso & Deruelle, 2009), and maltreated children (Luke & Banerjee, 2012). Given the stability of these early individual differences, and the obvious importance of emotion understanding to children's well-being, it is crucial to determine the antecedents, developmental trajectory and neurobehavioural basis of these skills.

Electroencephalography (EEG) is particularly suited to the study of paediatric populations (e.g. de Haan & Thomas, 2002). Although a great deal of research has been conducted into the Event Related Potentials (ERPs) associated with emotion perception and recognition (Eimer & Holmes, 2007), and emotion regulation (the ability to modulate emotional responses; Dennis & Hajcak, 2009), little research has been carried out to assess ERPs associated with emotion *understanding*. The neuroscientific studies most relevant to emotion understanding in children are those investigating cognitive Theory of Mind ('ToM'; e.g. Bowman, Liu, Meltzoff & Wellman, 2012; Liu, Meltzoff & Wellman, 2009; Liu, Sabbagh, Gehring & Wellman, 2004, 2009; Meinhardt, Kuhn-Popp, Sommer & Sodian, 2012; Meinhardt, Sodian, Thoermer, Dohnel & Sommer, 2011; Sabbagh, Bowman, Evraire & Ito, 2009; Sabbagh & Taylor, 2000).

ERP studies have reliably associated cognitive ToM with the presence of a late, anterior slow wave (the Late Positive Potential, or 'LPP'; Meinhardt et al., 2011). For example, Meinhardt and colleagues (2011), using a modified false-belief task, found that trials involving false belief elicited a larger amplitude LPP than trials involving true-belief, both in adults and 6-8 year old children. Similarly, Sabbagh and Taylor (2000) found that a greater left frontal positivity was elicited by tasks that required answering questions regarding mental representation (false belief) in comparison to questions requiring thought about a non-mental (photograph) representation.

Notably, although a difference in LPP for belief versus control tasks is quite robust, the direction of the effect appears somewhat task dependent. For example, Liu, Sabbagh and colleagues (2009) found a smaller LPP amplitude for belief questions compared to reality questions. In their study, children were shown film clips of false-belief eliciting stimuli. A cartoon character placed two animals in two different boxes; the character then stood in front of the boxes, and the animals were seen to move to different boxes, out of sight of the cartoon character. The participants were then asked a ‘reality question’ – ‘where is this animal really?’ and a ToM (belief) question ‘where does the person think this animal is?’. The participants either answered the questions verbally or by pointing. The researchers found an LPP 775 ms - 850 ms post stimulus, occurring at left-frontal electrodes, which was smaller (less positive) for belief reasoning, in adults, and among children who passed a ToM test. This effect was not seen in children who did not pass the ToM test, suggesting that the LPP may be a neural correlate of ToM processing.

Based on studies of adults, several structural brain regions have been implicated in ToM, including the posterior Superior Temporal Sulcus (pSTS), Temporo-Parietal Junction (TPJ), temporal poles and the medial Pre-Frontal Cortex (mPFC; Frith & Frith, 2006). Similar structural regions have been implicated in emotion understanding/affective ToM tasks in adults (e.g. Burnett, Bird, Moll, Frith & Blakemore, 2009).

Violation of Expectation

Violation of expectation is a technique that could be used to assess emotion understanding in children. Violation of expectation has been associated with an increased negative potential 400 ms post-stimulus (the 'N400') (Kutas & Federmeier, 2011). The N400 is thought to be associated with integrating new information with the current context, or with the access and retrieval of conceptual knowledge from Long Term Memory (Kutas & Federmeier, 2011). Typically, the violation of expectation-related N400 is found following the presentation of semantically unrelated verbal or written information, such as the presentation of pairs of semantically unrelated words or a word semantically unrelated to a context (Ibanez et al., 2012). However, the N400 is apparent across modalities, and recently has been demonstrated in studies of emotion processing. Leuthold, Filik, Murphy and Mackenzie (2012) presented adults with sentences describing the context of a scenario and the emotional response of a character involved in the scenario. These authors found a larger amplitude of the N400 (localised to the anterior temporal lobe), followed by a larger frontal positivity (LPP), when the emotional response was incongruent with the context. The authors propose that the LPP 'reflects high-level mindreading functions', which would be consistent with LPP findings in ToM studies. Conversely, the N400 was proposed to represent 'increased integration and semantic memory demands in the case of a violation of a socio-emotional stereotype' (Leuthold et al., 2012, p. 463). Analogous paradigms have been used to investigate cognitive ToM (e.g. Meinhardt et al., 2011).

The present study uses knowledge of the ERPs elicited by false-belief and violation of expectation paradigms to investigate neural correlates of emotion understanding in young children. Experiment 1 provides an initial exploration of ERPs potentially associated with emotion understanding. ERPs were reliably and consistently elicited by this paradigm, but due to the design, it was not clear whether these were associated specifically with understanding of emotions, or more generally with violations of expectations. Experiment 2 replicates the findings of Experiment 1 and explores the specificity of the response to emotion understanding.

EXPERIMENT 1

In order to investigate the neural correlates of emotion processing, we modified an existing task used by Steele, Steele, Croft and Fonagy (1999), which investigated emotion understanding in 6-year-olds. This is the earliest age at which the majority should have acquired emotion understanding and therefore be engaged by a task of emotion understanding. In this earlier study, 63 children of the same age group were shown cartoon-sequences, in which a cartoon character was firstly shown in a scene and with a corresponding emotion displayed on their face (e.g. a child with a smiling face holding an ice-cream). In the next image, the scene changed (e.g. the child has dropped the ice-cream) and the child's face was blank, with no facial expression. The child was asked to choose an emotional face which suited the final scene (i.e. to fill in the blank face). In the present study, similar stimuli were used to elicit cognitive processing associated with emotion-understanding by presenting children, in an event-related design, with emotional expressions that were either congruent (e.g. sad that they have dropped their ice-cream) or incongruent (e.g. happy that they have dropped their ice-cream) with the previous context. Incongruent scenes were expected to evoke a larger LPP component, reflecting the child's attempt to understand the character's unexpected emotional response. We also anticipated that incongruent emotions would elicit a larger N400 response.

Materials & Methods

Participants

Full ethical approval was gained from the university Research Ethics Committee. Participants were 46 children (24 males) and their mothers. Ages ranged from 69 to 81 months (Mean = 73.13, Standard Deviation = 2.63 months). Prior to completion of this study, parents were asked whether their child had any vision difficulties (that could not be corrected through the use of glasses), or any developmental disabilities including Autistic Spectrum Disorder – and any children whose parents reported that they did have one of these difficulties were excluded.

Three participants did not complete the EEG task, due to skin allergies and/or anxiety about the procedure. Data from 10 children were excluded due to excessive movement artefacts or technical errors during EEG recordings. Therefore, the final sample consisted of 33 children (14 males; Mean age = 72.88 months, Standard Deviation = 2.37 months; range = 69 -78 months).

EEG task

Participants viewed 40 cartoon scenarios, each comprising two or three static scenes. Audio description of the scenes accompanied each scenario. Each scenario involved a child character in an emotion-eliciting scenario (e.g. dropping their ice-cream). The next scene involved the child character with a blank face, where the participant was asked to think about how the child character was feeling. Finally, the character's facial expression (congruent or incongruent with the emotional context) was then revealed (Figure 1).

In half the scenarios, the scenario was such that a positive emotion was the expectable emotional response of the character (e.g., receiving a gold star at school), and in 20 a negative emotion was the expectable outcome (e.g. falling off a bicycle). Additionally, half the scenarios ended with a facial expression that was congruent (e.g. sad that they dropped their ice-cream), and half incongruent (e.g. happy that they dropped their ice-cream), with the context. Therefore there were four conditions (positive congruent emotion, positive incongruent emotion, negative congruent emotion and negative incongruent emotions), each with ten scenarios per participant. Each participant had 20 congruent scenarios and 20 incongruent scenarios. Scenarios were presented in a random order. Two versions of the task were created, and counterbalanced so that half of the participants viewed the congruent version of a given scenario and half viewed the incongruent version of the same scenario.

Procedure

Participants sat in a dark, sound attenuated room whilst the tasks were presented on a computer monitor, situated approximately 41 cm away from the participant. The images were approximately 18 cm^2, with subtended visual angles of 254º horizontally and vertically. Each ERP eliciting image (the image in which the facial emotion was shown), was presented for 2000 ms following the presentation of the same image without a facial expression. The inter-stimulus interval between scenes within a scenario was 0 ms, and between scenarios was 500 ms. The ERP data were time-locked to the presentation of the image in which the facial emotion was shown. Stimulus presentation was controlled using the E-Prime 2.0 Software (Psychology Software Tools, Pittsburgh, PA).

Electroencephalography (EEG) acquisition and preprocessing

EEG data were collected and recorded online using Electrical Geodesics, Inc. 129-channel sensor nets (Tucker, 1993), NetAmps Series 300 amplifier (Electrical Geodesics, Inc.) and NetStation software. The data were amplified and sampled at a frequency of 250 Hz and impedance was kept below 100 kΩ, as per the system recommendations. An anti-aliasing low-pass filter of 70 Hz was applied during data acquisition.

Data Analysis

Offline, the EEG data were band-pass filtered between 0.1 and 30 Hz and re-referenced to the average, using the EEGLAB software package (Delorme & Makeig, 2004).

Continuous EEG data were segmented into epochs between -200 ms and 1500 ms relative to stimulus onset. Spline interpolation was carried out on individual channels if required. Independent component analysis was run using FASTER to remove stereotyped artifacts (Nolan, Whelan & Reilly, 2010). Epochs were excluded from analysis if they met any of the following artefact rejection criteria: voltage deviations exceeded ±175 µV relative to baseline, the maximum gradient exceeded 150 µV, or activity was lower than 1 µV. Participants were excluded if more than 20 epochs (50%) were rejected; 2 participants were excluded due to this criteria.

ERPs were constructed by creating grand average wave-forms for selected electrodes and time periods, separately for all four stimulus conditions (negative congruent, negative incongruent, positive congruent and positive incongruent). The LPP was constructed from the midline Frontal electrode (Fz; electrode 11) waveforms, between 700 – 1495 ms. The N400 was constructed from the midline Central electrode (Cz; electrode 129), between 300 – 500 ms. Electrodes and time periods were selected based on the findings of previous research (e.g. Meinhardt et al., 2011). Mean amplitudes in the 200 ms window prior to the picture onset served as the baseline. At this stage, participants were excluded from analyses if the mean LPP amplitudes were greater than two standard deviations from the mean, or if visual inspection of the data revealed a significant amount of noise due to movement or technical error. This resulted in the removal of seven additional participants, giving a final sample of 33 participants.

For the final sample, the mean number of interpolated channels was 8.62 (*SD* = 4.33; range = 0-13 channels The range of accepted trials was equivalent across conditions. Across participants and conditions, a mean of 81.3% trials (SD =12.8%, range = 50%-100% trials) were retained after filtering and artefact rejections.

The mean number of epochs analysed per condition were 8.18 (SD=1.68, negative congruent), 8.52 (SD = 1.52, negative incongruent), 7.30 (SD = 1.79, positive congruent) and 8.55 (SD = 1.45, positive incongruent). Effects of congruency (congruent versus incongruent scenes) and emotional valence (scenes expected to end with a positive emotion versus those expected to end with a negative emotion) were examined with 2 x 2 (congruence x valency) fully within-subject GLM Analyses of Variance (ANOVAs) using Type III Sums of Squares. Mean amplitudes for selected time periods were used in all cases.

Results

Descriptive statistics are displayed in Table 1.

ERPs associated with violation of expectation

The LPP demonstrated significant effects of congruency (Figure 2), $F(1,32) = 27.818$, $p = <.001$, $\eta_\rho^2 = .465$, but not of valence, $F(1,32) = .336$, $p = .566$, $\eta_\rho^2 = .01$, nor any interaction between valence and congruence, $F(1,32) = .316$, $p = .578$, $\eta_\rho^2 = .01$. The N400 demonstrated no significant main effects of valence, $F(1,32) = 3.20$, $p = .083$, $\eta_\rho^2 = .091$, congruency, $F(1,32) = .289$, $p = .594$, $\eta_\rho^2 = .009$, nor interaction between valence and congruency, $F(1, 32) = 3.790$, $p = .060$, $\eta_\rho^2 = .106$.

ERPs associated with visual and face processing: N1, P1

To ensure that the LPP congruency effect was not due to differences in the basic visual properties of the stimuli (e.g. contrast), P1 and N1, which are known correlates of early visual processing (e.g. Anllo-Vento & Hillyard, 1996), were analysed. The P1 and N1 mean amplitudes showed no significant effects of congruency, $F(1, 32) = 3.284$, $p = .079$ (P1), $\eta_\rho^2 = .093$; $F(1,32) = 3.455$, $p=.072$ (N1), $\eta_\rho^2 = .097$, or valence, $F(1,32) = .282$, $p = .599$, $\eta_\rho^2 = .009$ (P1); $F(1,32)=.008$, $p = .928$, $\eta_\rho^2 < .001$ (N1), nor a significant interaction between valence and congruency, $F(1, 32) = .1.702$, $p = .201$, $\eta_\rho^2 = .05$ (P1); $F(1,32) = 1.557$, $p = .221$ (N1), $\eta_\rho^2 = .046$.

Demographics and ERP Components

A 2 x 2 (gender x congruency) ANOVA demonstrated an overall effect of congruence, $F(1, 31) = 26.006$, $p < .001$, $\eta_p^2 = .456$, but not of gender, $F(31,1) = .006$, $p = .939$, $\eta_p^2 = .051$, and there was no significant interaction between the two, $F(31,1) = 1.083$, $p = .306$, $\eta_p^2 = .034$. Age was not correlated with the congruence effect.

Experiment 1 Conclusion

Experiment 1 demonstrated that an LPP is associated with understanding the congruence between an emotional response and the associated situation. However, it is not clear whether this response is specific to understanding emotions, or more generally related to a violation of expectation. This is a critical issue in the broader literature on Theory of Mind and the LPP. As Lui & Sabbagh (2009) note, LPP differences related to false belief (versus reality) reasoning are associated with enhanced LPP amplitudes, which may reflect domain-specific neural mechanisms or domain-general ones such as working memory processes. False belief tasks, and our emotion understanding task, both involve the activation of a representation within working memory (the actor's expected emotion in our task or the actor's belief about an object location in false belief tasks) which may then be violated by the outcome and require additional processing to integrate the context and outcome into working memory. One way to test whether the processes reflect domain-specific versus domain-general mechanisms is to include a control task that has similar working memory demands and violations of expectation, but no social-cognitive processing.

EXPERIMENT 2

To extend these findings a second experiment was conceived, aiming to clarify whether the greater LPP observed in relation to incongruent emotional outcomes was a specific neural correlate of emotion understanding, or an index of emotion understanding which was also present with unexpected physical outcomes. It further aimed to correlate EEG findings with self-report data on emotion understanding using the Test of Emotion Comprehension (TEC; Pons & Harris, 2000).

Methods

Participants

Full ethical approval was gained from the university Research Ethics Committee. Participants were 43 children (18 males), aged between 62 and 89 months (Mean = 76, Standard Deviation = 8 months). The same exclusion criteria applied. Data from 7 children were excluded, 1 due to technical error and 6 due to excessive movement artefacts. Therefore, the final sample consisted of 36 children (15 males; Mean age = 76 months, Standard Deviation = 8 months; range = 64 - 89 months).

Procedure

EEG task. Participants viewed 24 of the original 40 cartoon scenarios that were used in Experiment 1 (e.g., a child drops her ice cream, and her emotional response is positive or negative). Twelve positive and twelve negative stories were used, and combined to create two conditions – congruent and incongruent.

In addition, 24 physical stories were used (see Figure 3. for sample item), 7 taken from a set of physical causality stories validated by Sebastian et al. (2012), which were adapted from stories developed by Völlm et al. (2006). These were developed to require no understanding of the mental states of the characters (emotional or cognitive), only an understanding of cause and effect. The 24 physical stories were to resemble the emotion stories and were presented in an identical fashion, except that the voiceover question for the penultimate image asked: “I wonder what will happen next – shall we see?”. Each physical story had an expected and unexpected outcome which could be clearly illustrated in the final image, which was otherwise identical to the penultimate image. Although these stories were designed not to evoke specific emotion-related processing, it is possible that some of the stories may have evoked emotions in the children watching or inferred on the part of the character in the story (for example, a sandcastle being washed away may have caused some children to feel sad, or to infer that the character who made it would be sad). In post-hoc analyses we further separated the stories into those that were clearly emotionally neutral (14/24) versus those with some emotional element (12/24).

Participants were shown 12 stories for each of the 4 conditions: emotionally congruent, emotionally incongruent, physically expected and physically unexpected. Two counterbalanced versions of the task were created so that every participant saw each story only once. In this way, each child received all of the emotional and all of physical stories (including those with emotionally neutral content and those with possibly emotional content). The endings of the stores were counterbalanced so that half were expected and half were unexpected. Because different instructions were needed for the physical versus the emotional task, they were kept separate with all stories of one type shown first, but with a counterbalanced order of presentation across trials. Within each story type (physical or emotional), stories were presented in a random order. The EEG equipment, protocol, acquisition and preprocessing remained as outlined in Experiment 1

TEC (Pons & Harris, 2000). The TEC was chosen as a standard comparison measure of emotion understanding. It uses a picture book with simple cartoon scenarios to investigate different elements of emotion understanding. Each question is illustrated with a single cartoon image of a child with no facial features, and can be answered by pointing to one of the four possible cartoon facial expressions: happy, just alright and two of sad, scared or angry. Answers are scored to give a total emotion comprehension score between zero and nine. A detailed description of the materials and procedure can be found in Pons and Harris (2005). The average score in this sample was 6.14 (SD = 1.62).

Data Analysis

EEG data was processed as outlined in Experiment 1 using GLM ANOVA and type III sums of squares. For the final sample, the mean number of interpolated channels was 7 (SD = 4; range = 0-13 channels). Across participants, a mean of 87.5% of trials (SD = 9.7%; range = 62.5-100%) were retained after filtering and artefact rejections. The mean number of epochs analysed per condition were: 10.58 (SD = 1.42; emotion congruent), 10.78 (SD = 1.47; emotion incongruent), 10.61 (SD = 1.39; physical congruent) and 10.47 (SD = 1.73; physical incongruent). ERP data were correlated with the scores from the TEC. Effects of congruency (congruent versus incongruent scenes) and story type (emotional or physical) were examined with 2 x 2 (congruence x type) fully within-subject Analyses of Variance (ANOVA). Mean amplitudes for selected time periods were used in all cases.

Results

Results are presented in three parts. First, we attempted to replicate the findings of Experiment 1 by again analysing the potential neural correlate of emotion understanding (the LPP). We analysed electrodes and time-periods for the LPP which had shown a link in Experiment 1. Second, other ERPs associated with violation of expectation (the N400) and early visual processing (the N1 and P1) are reviewed. Finally, we present results regarding the association between ERPs and TEC scores.

ERP data

Descriptive statistics, along with the selected electrodes for each ERP, are outlined in Table 2. Significance is considered at the .05 level. Greater mean amplitudes were found for the LPP in incongruent conditions (compared to the congruent ones), and a greater mean amplitude was shown for the N400 in the emotional incongruent condition. N1 mean amplitudes were greater for the physical than emotion conditions and the P1 showed no clear pattern of means. Consistent with this, there were two significant findings: the LPP demonstrated a significant main effect of congruency, showing higher amplitudes for incongruent conditions, whereas the N1 demonstrated a significant effect of type, showing a greater negativity in emotion conditions.

LPP associated with emotional understanding (see Figure 4). The LPP demonstrated significant effects of congruency, ($F(1,35) = 9.090$, $p = .005$**, $d = .96$) but not of type, ($F(1,35) = 0.441$, $p = .511$ n.s.), nor any interaction between type and congruence, $F(1,35) = 0.208$, $p = .651$, n.s.).

N400 associated with violation of expectation. The N400 demonstrated no significant main effects of type, $F(1,35) = 1.462$, $p = .235$ n.s.; nor congruency, $F(1,35) = 26.858$, $p = .186$ n.s, nor interaction effect, $F(1,35) = 0.715$, $p = .804$ n.s.

ERPs associated with visual and face processing: N1, P1. To ensure that the LPP congruency effect was not due to differences in the basic visual properties of the stimuli (e.g. contrast), P1 and N1, which are known correlates of early visual processing (e.g. Anllo-Vento & Hillyard, 1996), were analysed (Figure 5). The P1 and N1 mean amplitudes showed no significant effects of congruency $F(1,35) = .664$, $p = .421$ n.s.; $F(1,35) = .108$, $p = .744$ n.s. and no significant interaction between valence and congruency, ($F(1,35) = 1.917$, $p = .175$ n.s.; $F(1,35) = 1.562$, $p = .220$ n.s. The P1 showed no significant effect of type $F(1,35)$

= 1.066, $p = .309$ n.s., but the N1 did demonstrate a significant effect of type $F(1,35) = 16.907$, $p < .001$** with larger negativity for emotion conditions.

Demographics and ERP Components

ERP components were analysed in terms of gender and age to determine if there were any significant effects of these variables. No significant effect of age or gender was found.

TEC and ERP comparison

Questionnaire scores from the TEC were compared with the ERP components. No significant associations were found (all $p>0.05$).

Post hoc analysis

When designing the stimuli for Experiment 2 we wanted to keep the stories and visual stimuli as close as possible to those used in Experiment 1. This required that the stories involved human characters. Although we aimed to develop stories that would not evoke specific emotions, it is difficult to completely remove emotional responses from stories involving human characters and some stories may evoke emotions in the children watching. To check what impact having some trials in the physical condition with potentially emotion-evoking outcomes might have had on the LPP, we identified physical stories that were clearly emotionally neutral and those that had some emotional element. Fourteen of the stories had no discernible emotional outcome (e.g., a ball appears where expected or in a different location) and 10 had some emotional element to the outcome (e.g., the dolls hat does or does not fit - which may imply sadness; or an egg smashes or bounces – where the egg smashing may elicit sadness).

Re-running the EEG analysis with the physical stories separated into these two separate conditions revealed a main effect of expected versus unexpected outcomes for the LPP ($F_{1,31} = 4.55$, $p = .027$), no main effect of story type (purely neutral versus having an emotional element; $F_{1,31} = 1.03$, $p = .31$, and no interaction between expected versus unexpected outcome and story type ($F_{1,31} = 1.29$, $p = .27$).

Analysing each story type separately revealed that the purely neutral stories showed no reliable main effect of expected versus unexpected outcome ($F_{1,31} = .33$, $p = .57$). In contrast, the stories that contained some emotional element did show a main effect of expected versus unexpected outcome ($F_{1,31} = 6.63$, $p = .015$). It should be noted that this analysis is based on a small number of trials per condition – to retain the majority of cases in the analysis we had to retain epochs that had a minimum of three trials. The average number of trials in the purely neutral condition was 6.44 (expected) and 6.10 (unexpected), whereas for the ‘emotional element’ condition the mean number of trials was 4.38 (expected) and 4.56 (unexpected). It should also be noted that when we re-ran the analysis of the comparison between emotional and physical stories, excluding all potentially emotion-containing trials from the physical condition, the interaction between expected versus unexpected outcome and story type (emotion versus physical) remained non-significant ($F_{1,29} = .26$, $p = .61$), although when analysed separately the effect of expected versus unexpected outcome was only significant in the emotion condition ($F_{1,29} = 7.37$, $p = .011$), and not the physical condition ($F_{1,29} = .74$, $p = .40$).

DISCUSSION

This study aimed to explore neural correlates of emotion understanding. Experiment 1 found a late LPP for emotionally incongruent outcomes. Experiment 2 investigated whether this neural correlate was specific to social-cognitive processing, such as emotion understanding, as opposed to a more general effect of congruency. This Experiment compared the impact of congruence on emotional and physical stories, and found a main effect of congruent, but no congruence x story type (physical versus emotional) interaction. On the face of it, the study therefore points towards the possibility that the LPP elicited by our emotion understanding task reflects comparatively domain general cognitive processing linked to congruency detection or processing, rather than indexing uniquely social-cognitive processing. However, further post-hoc analysis following Experiment 2, in which the physical stories that contained possible emotional content were removed from analysis, casts doubt on this conclusion. These results provided some preliminary indication that the LPP may selectively index emotional/social processing. Such a possibility warrants further investigation.

Neural Correlates

LPP

Experiment 1 demonstrated that an LPP is generated when processing unexpected outcomes (unanticipated emotional responses) in a task involving emotional understanding. This result was replicated in an independent sample in Experiment 2. The findings suggest that, like similar studies of cognitive theory of mind, the LPP is sensitive to children's understanding of social agents' inferred affective states. Across the two experiments, the congruent and incongruent scenes can be assumed to require approximately equal levels of general processing and so the LPP effect can be attributed to the additional cognitive demand of making sense of the incongruent outcomes. The lack of a significant interaction between congruence and story type for LPP amplitudes in Experiment 2 however may imply that the enhanced LPP is not exclusively a neural correlate of emotion/mental state understanding, but rather reflects more domain-general cognitive processing, perhaps related to context-outcome integration and associated conceptual and working memory operations. However, some of the stories used in Experiment 2 had social or emotional aspects (e.g., a vase is dropped and smashes, versus bounces), which limits how strongly we can conclude this on the basis of the current findings alone. Further, post-hoc analyses conducted after experiment 2 revealed that the difference in LPP amplitude was not reliably observed in the subset of ‘purely’ physical stories where the outcomes were entirely emotionally neutral. It was only in the physical stories that had some emotional aspects that we observed a reliable LPP difference between expected and unexpected outcomes. This may suggest that the LPP is indeed specific to emotion or social understanding. However, it is important to note that these were post-hoc analyses based on small numbers of trials, and that a formal test of the difference in LPP amplitude between the purely neutral physical stories and those with emotional content was not significant.

N1 & P1

In Experiment 2, a significant difference was also found between emotional and physical conditions (though not congruency) in the early visual processing component N1, with emotion conditions showing a greater negativity than physical conditions. Greater N1 amplitudes have been found in response to stimuli in attended compared to unattended locations (Anllo-Vento & Hillyard, 1996). In the present study, emotion outcomes always appeared within the face outline shown on the previous image, so attention can be focused on this area, whereas physical outcomes can be shown in different parts of the image and are not always as clearly cued as the emotion outcomes. This may have resulted in emotion outcomes (but not physical outcomes) being presented in the attended visual field and therefore generating greater N1 amplitude responses.

However, in previous studies, greater P1 amplitudes have also been found for attended compared to unattended locations (Anllo-Vento & Hillyard, 1996), whereas in this study the P1 component was not found to be significantly different between conditions. This suggests that instead of a function of attention, it may be the emotional content of emotion stimuli that is responsible for the greater N1 amplitude. Foti, Hajcak, & Dien (2009) found that positive or negatively valenced images (including happy and sad faces) elicited greater N1 responses than neutral images. The neutral physical stimuli may therefore have resulted in smaller N1 responses than the happy and sad faces in the emotion stimuli.

N400

The study found no significant difference in N400 components between any of the conditions. The N400 is thought to indicate a violation of semantic expectation and so one possible explanation would be that the incongruent conditions did not surprise the participants (did not violate their expectations). However, this is not supported by unprompted verbal comments and facial expressions made by participants expressing surprise at the outcome of emotion incongruent and physical unexpected stories, nor with the observed congruency differences across both story types on the LPP. It is therefore necessary to consider why the current results were limited to the LPP and not the N400. Other studies investigating the impact of congruence have reported significant effects on LPP but not on N400 (pairs of emotional stimuli; Herring, Taylor, White & Crites, 2011), or have found significant effects on both (incongruent behaviour by a character in a story; Baetens, van der Cruyssen, Achtziger, Vandekerckhove & van Overwalle, 2011). This has been understood as demonstrating that N400 increases as additional *effort* is required to make sense of the inconsistent information, whereas LPP increases as additional *attention* is paid to evaluate the incongruent information (Baetens et al., 2011). It may be that the current task, possibly because it did not require the child to explicitly use the outcome information or provide a response, elicited attentional processes geared to integrating the context and outcome information but not effortful semantic analysis per se. It may also be that the neural processes are different in the developing brain compared to adults.

Such an interpretation may help explain why we observed no significant effect on the N400. Studies have shown that the N400 response is most pronounced for semantically incongruent outcomes when participants have to actively respond, and diminishes for passive tasks where the instruction is to listen and watch (Erlbeck, Kübler, Kotchoubey, & Veser, 2014). In the present study children were instructed to watch and think about the story, but not to actively respond. It may be that the passive nature of the task diminished the N400 response to a level where no significant differences could be observed between congruent and incongruent conditions. It would be useful for a future study to use an active task (requiring a key press for example), which would allow investigation into whether this aspect of the task was responsible for the lack of difference in N400 amplitudes between conditions. By asking for a response it would also be possible to see if the lack of an active response was what led to the failure to observe a difference in the N400 between congruent and incongruent conditions. However, the additional information gained would need to be weighed against the likely increase in movement artefacts as a result of instructing young children to respond.

ERP and TEC

The present study aimed to correlate ERP components with self-report data on emotion understanding, in order to address the question of whether individual differences in emotion-understanding-related EEG responses might capture individual differences between children in their emotional understanding competence. However we found no significant association between TEC score and ERP components. It therefore remains an open, and important, question whether individual differences in the LPP can reveal reliable information regarding individual differences in children's emotional understanding. It is possible that the LPP does not capture individual differences in emotion understanding with sufficient reliability. We would, however, be cautious to conclude that at this point, because other alternative methodological explanations may account for the lack of association.

Although both tests investigate emotion understanding, the EEG task looked specifically at affective perspective taking, whereas the TEC assesses nine different components of emotion understanding including understanding of mixed and hidden emotions. It may be that the TEC investigates more advanced emotion understanding skills, whereas the EEG task examines information processing related to more basic emotion understanding. We would expect that most children in our sample would have understood the ‘correct’ answers to the EEG scenarios, and so individual differences in EEG response are likely to reflect differences in emotion processing efficiency rather than the presence or absence of understanding per se. It would be interesting for a future study to repeat the task with younger children, who may not all ‘pass’ the EEG task and see if a relationship between ERP response and TEC score is then found.

An alternative explanation might be that the two tasks differ in the degree of automaticity involved – the EEG task likely measures immediate, and rapid, cognitive processing that takes place when an unexpected outcome occurs, whereas the TEC allows the child to give a considered answer over a period of time. Furthermore, the TEC requires the child to make an explicit decision about what the ‘correct’ emotion is, while the EEG task does not. These differences may lead them to tap into quite different individual differences. It is also worth noting that although the TEC does not require a verbal response, language ability has been shown to explain a significant amount of the variance in self-report emotion understanding tasks: in a comparison using the TEC, language explained 27% of the variance in emotion understanding (Pons, Lawson, Harris & de Rosnay, 2003). It may be that language ability affects the children’s performance on explicit tests like the TEC, which may not be the case in the EEG task . As a brain-based measure, the EEG task reduces the reliance on language and therefore is less likely to be affected by language ability. In future studies, the addition of a language ability measure would allow relationships between language level and emotion understanding to be investigated further. In general, further work is warranted investigating whether individual differences in LPP response to emotion-understanding tasks are reliable indicators of emotion-related functioning in children.

Conclusion

In conclusion, we find consistent evidence that the LPP is a neural index of cognitive processing that can be deployed to probe young children's emotion understanding. The findings may shed light on the broader question of the domain-specificity or generality of the processes giving rise to the LPP in social-cognitive research. As a brain-based measure it may also allow more accurate assessment of emotion understanding skills, with less reliance on language than traditional self-report measures and could be extended to investigate neural differences in affective perspective taking in ASD or other populations where social and emotional functioning may be impaired. Further studies that include a wide range of ages or longitudinal data would be invaluable in order to elucidate developmental changes in the neural systems supporting emotion understanding. Overall, our findings were equivocal about whether the LPP reflects domain general attentional, working memory and context-outcome integration processes, or domain-specific mechanisms unique to emotional and social understanding.

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