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Empathy is associated with dynamic change in prefrontal brain electrical activity during positive emotion in children

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Abstract

Empathy is the combined ability to interpret the emotional states of others and experience resultant, related emotions. The relation between prefrontal electroencephalographic asymmetry and emotion in infants and children is well known. The relationship between positive emotion (assessed via parent-report), empathy (measured via observation) and second-by-second brain electrical activity (recorded during a pleasurable task) was investigated using a sample of 128 six to ten year olds. *Contentment* predicted increasing left-sided frontopolar activation (p<.05). *Empathic concern* and one form of *positive empathy* predicted increasing right-sided frontopolar activation (ps<.05). A second form of positive empathy predicted increasing left-sided dorsolateral activation (p<.05). This suggests that positive emotion and (negative and positive) empathy predict changes in prefrontal activity in children during a pleasurable task.

Empathy refers to a change in emotional state that results from contemplating someone else's emotional state and experiencing an emotion (or set of emotions) that is similar in quality to the emotion experienced by another person. An empathic change in emotional state occurs when an internal representation of the emotional state of the target is generated *along with* a feeling of goodwill in the empathizer. Embedded in this definition is the idea that in order for empathy to occur, a *dual* representation of the emotional state of the empathizer and the target must be instantiated in some way in the brain of the empathizer. Once such a dual representation is formed in the mind of the empathizer, a new (i.e. second order) affective state may take shape. The formation of this conglomerate affective state results from the partial mergence of one's own affective state (which must include some feeling of goodwill in addition to any other type of feeling) and the affective state of another person. Based on this model of empathy, there are several individual characteristics that are expected to be associated with greater empathic

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ability (Decety & Moriguchi, 2007), including: the tendency to become the object of one's own attention (i.e. individuals who are dispositionally more introspective and reflective are more likely to be empathic), and the tendency to be able to flexibly shift between one's own emotional state and the emotional state of someone else (i.e. cognitive/emotive flexibility). Interestingly, the development of the ability to be introspective and exert increasing levels of cognitive control relate to the development of the prefrontal cortex (Decety & Moriguchi, 2007).

Empathy is considered to be a complex emotional process because it emerges later in development compared to basic emotions such as happiness and fear, and empathy can involve the experience of blended emotion—that is to say, the same (or similar) emotion that is perceived in someone else is conjured up along with an other-oriented emotion such as goodwill, concern or tenderness. The term "empathy" is often used to refer to the vicarious sharing of another's pain or sorrow (Ikes, 1997). This form of empathy can be described as *empathic concern* (Zahn-Waxler, Radke-Yarrow, Wagner & Chapman, 1992; Zahn-Waxler, Robinson, & Emde, 1992; Hastings, Zahn-Waxler, Robinson, Usher & Bridges, 2000) because the empathizer is relating to the negative emotion of another person.

Empathic Heterogeneity

Empathic concern may only capture one aspect of the empathy spectrum. We contend that at least two other forms of empathy exist and should be studied. For example, an individual may exude positive emotion while in the presence of someone who is experiencing a negative emotional state as a means to alleviate the negative emotion that person is feeling by catalyzing a positive emotional state in that person. This phenomenon can be referred to as *empathic cheerfulness*. Furthermore, an individual may vicariously experience pleasure in response to someone else's positive emotion. This phenomenon can be referred to as *empathic happiness*. Collectively, *empathic concern, empathic happiness* and *empathic cheerfulness* can be referred to as "empathy subtypes" (Table 1).

Furthermore, though the idea that empathy can occur in response to the positive emotional displays made by someone else has been proposed (Lipps, 1903), no psychological theory of empathy has *explicitly* incorporated the idea of empathic heterogeneity—the existence of negative (e.g. *empathic concern*) and positive valence empathy (e.g. *empathic happiness* and *empathy cheerfulness*)—into a neurophysiological research framework. To our knowledge, the distinct characteristics of negatively versus positively valenced forms of empathy (e.g. *empathic concern* versus *empathic cheerfulness* and *empathic happiness*) have not been examined empirically; with the exception of Jabbi, Swart, M. & Keysers (2007), who examined the similarity between tasting something sweet and observing someone else tasting something sweet. However, it can be argued that the type of empathy examined in that study is distinct from the type of empathy introduced here because *empathic happiness* and *empathic cheerfulness* involve a feeling of goodwill toward someone, whereas vicariously relating to someone drinking a pleasant-tasting liquid does not. Therefore, one of the key contributions of the present paper is the distinction between higher level forms of negative and positive forms of empathy.

The relationship between the ability to experience basic emotions and the ability to experience empathy

The ability to experience *empathic concern, empathic happiness* or *empathic cheerfulness* may relate to the other emotive characteristics we possess. For example, an individual's general ability to experience positive or negative emotion may contribute to that individual's ability to empathize with the positive or negative emotion exhibited by someone else. The relationship between *empathic concern* and the tendency to experience negative emotion has been investigated empirically. For example, greater fear at 13.5 months of age predicted greater empathy at 7 years of age (Rothbart, Derryberry & Hershey, 2000). In adults, neuroticism, the tendency to experience negative emotion, was weakly correlated with the ability to experience *empathic concern* (Davis, 1996). In fact, many researchers have suggested that the tendency to experience substantial negative emotion leads to the expression of high levels of personal distress rather than empathy (Davis, 1996; Eisenberg, Fabes, Murphy, Karbon, Maszk, Smith, O'Boyle & Suh, 1994; Young, Fox & Zahn-Waxler, 1999).

The relationship between *empathic concern* and the tendency to experience positive emotion has received much less empirical attention, though the results from two studies suggest that there is a positive relationship between *empathic concern* and the tendency to experience positive emotion. Robinson, Emde & Corley (2001) found a significant and positive relationship between *empathic concern* and hedonic tone (the tendency to experience positive emotions) in a sample of toddlers aged 14 months. Furthermore, ratings collected from the caregivers of 80 children aged 6-7 years old indicated that there is a positive association between *empathy* and *low intensity pleasure* (Rothbart, Ahadi & Hershey, 1994). The *low intensity pleasure* scale assesses the child's tendency to experience enjoyment in situations involving mellow, non-risky stimuli. This construct seems to share conceptual space with contentment—an emotional state characterized by feelings of calm happiness. Similarly, Eisenberg et al. (1994) found that positive emotionality related positively to sympathy in a sample of adults. Together, these results suggest that our (children and adults alike) ability to experience positive emotion may be related to our ability to experience empathy.

To our knowledge, there is no comparable information about whether a relationship exists between the tendency to experience positive or negative emotion and the tendency to experience *empathic happiness* or *empathic cheerfulness*.

Activity in the prefrontal cortex correlates with the tendency to experience basic emotions

Though there is considerable information available about the association between the experience of basic emotions (e.g. joy, fear, etc.) and prefrontal cortex activity, there is a relative dearth of information about the relationship between prefrontal cortex activity and the ability to experience *empathic concern*, *empathic happiness* or *empathic cheerfulness*. For example, prefrontal brain electrical asymmetries recorded from the scalp surface have been found to be associated with the experience and/or expression of some basic emotions in infants, children, and adults. Specifically, it has been consistently shown that the experience of withdrawal-related negative emotion is associated with increased right-sided activation and the experience of approach-related positive emotion is associated with increased left-sided activation (e.g., Davidson & Fox, 1982; Davidson, 2004).

Many prefrontal regions have been implicated in the representation of emotion sub-components and emotion regulation. Electrophysiological and neuroimaging data suggest that increased activity in the dorsolateral (Davidson, Pizzagalli, Nitschke, Putnam, 2002; Herrington, Mohanty, Kovan, Fisher, Stewart, Banich, Webb, Miller, & Heller, 2005; Pizzagalli, Oakes, Fox, Chung, Larson, Abercrombie, Schaefer, Benca & Davidson, 2004), orbitofrontal (Nitschke, Nelson, Rusch, Fox, Oakes, & Davidson, 2004; Kringelbach & Rolls, 2004), ventromedial (Hamann, Ely, Hoffman & Kilts, 2002), and frontopolar cortex (Pochon, Levy, Fossati, Lehericy, Poline, Pillon, Le Bihan, Dubois B, 2002; Kensinger & Schacter, 2006) predict the experience of basic positive emotions such as happiness and/or pleasure. Nevertheless, little is known about the relationship between prefrontal cortex activity—particularly prefrontal EEG asymmetry—and empathic emotion, even though the literature provides reason to believe that a positive relationship exists between the experience of some basic positive emotions and empathic emotion. Given the known functions of the prefrontal cortex, we hypothesized that the prefrontal cortex plays an important role in mediating the relationship between the experience of basic positive emotions and the experience of empathic emotion.

The role of the prefrontal cortex in empathy

The prefrontal cortex is a structure that plays an important role in a variety of functions, including: (1) emotional processing—Nauta (1971) viewed the frontal cortex as “the major, although not only, neocortical representative of the limbic system (pg 182);” (2) executive functioning, including working memory, emotion regulation, and self monitoring (Miller & Cohen, 2001); and (3) learning (Miller & Cohen, 2001). In general, the prefrontal cortex organizes information from lower levels of processing (e.g. the limbic system, sensory systems) and uses that information to orchestrate thought, emotion, and motor actions in accordance with internal goals. The role played by the prefrontal cortex in emotional processing and executive functioning make this region particularly interesting to study in relation to empathy because the occurrence of empathy depends on the ability to (1) hold emotional information in mind (e.g. a function that requires intact working memory ability), (2) switch attention or concentration between one's own emotional state and the emotional state of the object (e.g. a function that requires cognitive flexibility), and (3) orchestrate an appropriate emotional response that makes use of the information held in mind about one's own emotional state and the emotional state of the object (e.g. a process that likely involves emotion regulation and self monitoring ability). Data from neuroimaging (fMRI and PET), electrophysiological (ERP) and lesion studies support the idea that the prefrontal cortex is an important node in the circuitry that supports the ability to feel what someone else is feeling.

fMRI—Singer, Seymour, O'Doherty, Kaube, Dolan & Frith (2004) used their data to emphasize an “empathy for pain network” that includes the anterior cingulate cortex and insula. However, in addition to activation in these two brain regions, the (adult) participants in that study also showed significant activation in the lateral prefrontal cortex when viewing their romantic partner receive a painful stimulus, but not when they received the painful stimulus themselves. This result suggests that the lateral prefrontal cortex may play a role in representing the affect of someone else. Nevertheless, the potential contribution of lateral prefrontal cortex activity in the empathy process was not incorporated into the authors' conceptualization of an empathy (brain) network. Similarly, healthy (adult) controls showed increased activity in left lateral prefrontal cortex in response to watching painful stimuli (Moriguchi, Decety, Ohnishi, Maeda, Mori, Nemoto, Matsuda & Komaki, 2007).

Jackson, Meltzoff & Decety (2005) found that there was a significant increase in frontopolar activity (BA 10) when adult participants thought about someone else's pain. Furthermore, Ruby & Decety (2004) found that the frontopolar cortex became more active when adult participants had to respond to emotionally evocative situations from the perspective of another person compared to when participants had to take a first person perspective.

Similarly, increased activation in dorsolateral (Brodmann Area 9) and frontopolar (Brodmann Area 10) regions of the prefrontal cortex were observed in adult participants who had to concentrate on their own emotional reaction to pictures of human faces *and* when they had to concentrate on what the person in the picture was feeling (Schulte-Rűther, Markowitsch, Fink & Piefke, 2007). Given that a common prefrontal network was activated by both the self-focused and other-focused task (i.e. dorsolateral and frontopolar prefrontal cortex), these results indicate that the prefrontal cortex is active during empathic processing.

Data from a recent neuroimaging study provide insight into how we respond to someone who is experiencing pleasure or disgust as a result of drinking a sweet or bitter beverage. fMRI images were collected as participants viewed someone else drinking a sweet or bitter liquid compared to a neutral liquid (Jabbi, Swart & Keysers, 2007). Self report measures of empathy were collected in order to determine whether brain activity that occurred in response to viewing facial expressions of other people's gustatory emotions was predicted by empathy. The results indicate that in addition to activations in regions that generally become active when we experience different tastes (both pleasant and unpleasant) ourselves (i.e. anterior insula and adjacent frontal operculum), participants who viewed someone else drinking a sweet or bitter liquid also tended to exhibit activations in the prefrontal cortex, particularly in the superior frontal gyrus (a region that includes frontopolar cortex). This study is informative because it suggests that prefrontal cortex activation does indeed occur when we empathize with the positive emotion of someone else; not just when we empathize with the negative emotion of someone else. Furthermore, this study indicates that prefrontal activity can be observed in empathic situations that involve a visual-gustatory processing component, building on the Singer et al., paper that provided evidence that the prefrontal cortex is involved visual-somatosensory forms of empathy.

Lesion—Lesion studies also offer some insight into the relationship between prefrontal cortical function and empathy given that empathy impairment is a central symptom of frontal lobe injury (Eslinger, 1998; Shamay-Tsoory, Tomer, Berger & Aharon-Peretz, 2003). For example, patients with dorsolateral PFC lesions exhibit empathy *and* cognitive flexibility deficits (cognitive flexibility refers to the ability to spontaneously generate ideas and switch from one idea to another as needed; Grattan, Bloomer, Archambaullt & Eslinger, 1994). This led some authors (Grattan & Eslinger, 1989; Eslinger, 1998) to put forth two hypotheses about the origin of the positive relationship between cognitive flexibility and empathy: (1) cognitive flexibility skills are a prerequisite for empathy ability; and (2) empathy and cognitive flexibility skills share common neuropsychological underpinnings.

PET—Data from Positron Emission Tomography (PET) studies also lend support to our contention that the prefrontal cortex plays a role in empathy. For example, superior frontal gyrus activation (e.g. Brodmann areas 9 and 10) was found to positively correlate with empathy level (Shamay-Tsoory, Lester, Chisin, Israel, Bar-Shalom, Peretz, Tomer, Tsitrinbaum & Aharon-Peretz, 2005). Participants were read an empathy-inducing story and then they had to respond to questions posed by an interviewer, such as: “what is passing through that person's mind?” The authors suggested that the positive association between empathic accuracy and prefrontal brain activity may indicate that the occurrence of empathy relies on an ability to exert cognitive flexibility, which allows for the observer to attend to the mental state of another person and generate creative—internally generated—responses.

ERP—Data from a recent electrophysiological study shed light on how the empathy response unfolds over time. Event-related potentials (ERP's) were recorded from healthy adults who viewed pictures of hands that were in painful or neutral situations (Fan & Han, 2008). The results indicate that the neural activities related to the pain condition were temporally dissociable. An early component over the anterior frontal area of the scalp emerged at 140 milliseconds after the images of painful situations were presented (relative to the presentation of neutral images), and a late component over the parietal area of the scalp emerged after 380 milliseconds of stimulus presentation. Furthermore, the participant's rating of their feelings of unpleasantness depicted in the images, were *both* correlated with the amplitude of the early frontal ERP component. The authors concluded that this finding suggests that the neural representation of someone else's pain can be automatically activated by the perception of that person in a painful situation, and can—at the same time—stimulate a similar emotional response in the empathizer. In order words, perceiving the pain of someone else overlaps temporally with the generation of one's own emotional response to the stimulus. Importantly, these data suggest that not only is the prefrontal cortex involved in empathy, but the prefrontal cortex becomes active *before* some other regions of the brain, given that the prefrontal component emerged by 140 milliseconds whereas the parietal component emerged after 380 milliseconds (Fan & Han, 2008).

What are the lateral and anterior PFC regions of the brain doing in empathy?

Moll, Eslinger & Oliveira-Souza (2001) assert that the prefrontal cortex needs to be thought about in terms of functional heterogeneity, "with polar, dorsolateral and orbital sectors mediating distinct, but complementary roles in the regulation of social cognition and behavior" (p. 663).

A few researchers have put forth ideas about how various regions of the prefrontal cortex contribute to empathy (Decety & Moriguchi, 2007; Shamay-Tsoory, Tibi-Elhanany & Aharon-Peretz, 2007). For example, the dorsolateral activity observed in various studies of empathy may relate to the empathizer's ability to internally represent the emotional state of the other person. This view is supported by other data in the literature that highlight the role that the dorsolateral region plays in allowing us to hold internal representations of external stimuli. The ability to form and hold an internal representation of someone else's emotional state may provide an avenue for the empathizer to experience an emotional state that is similar to the target's (Brothers, 1990; Preston & DeWaal, 2002).

One interpretation of the engagement of frontopolar activity during empathy tasks incorporates the involvement of this region in the generation, monitoring, and manipulation of self-generated information (Decety & Moriguchi, 2007). Adopting the emotional state of another person—and the instantiation of a new, compound emotional state that is characterized by the onset of feelings that are similar to the target's and also feelings of goodwill—likely requires an internal representation of the emotional state of the target to be formed in the mind of the empathizer. The internal representation of the emotional state of the target likely leads to the formation of self-generated ideas *and* self-generated emotion within the empathizer; a mental analogy is formed between one's own emotional state and the emotional state of the target. In essence, frontopolar cortex activity may operate to create a second order emotional state in the empathizer that is based on the information held in mind about the internal state of the target and one's own internal state. Similar to our conceptualization, Shamay-Tsoory et al. (2007) postulated that the anterior prefrontal cortex may become active when two or more emotional states—such as one's own, as well as the target's emotional state—must be processed simultaneously and integrated in some way in order for a higher order, empathic emotional state to form.

Summary

The data from a growing body of research utilizing a wide variety of methods—including fMRI, lesion, and electrophysiological measures—indicate that the dorsolateral and frontopolar regions of the prefrontal cortex are involved in empathic processing. However, precisely how these regions contribute to empathy, how they dynamically change over time, and how their role in emotion and empathy may overlap or differ requires further study.

Our study design provided a means to determine (1) whether prefrontal cortical activity relates to empathy in children in a similar manner as observed in adults, and (2) the relation between prefrontal cortical activity during emotional experience and the ability to display empathy. Specifically related to the second aim, we were interesting in determining whether basic *positive* emotional states (such as contentment) would relate to empathy, given that it is known that both empathy (e.g. Fan & Han, 2008; Lamm, Nusbaum, Meltzoff & Decety, 2007) and positive emotional experience (e.g. Gable & Harmon-Jones, 2008) are associated with engagement of prefrontal cortex. This question has received considerably less empirical attention than the predominant focus on the relationship between negative affect and empathy.

Is there a relationship between prefrontal cortex function in children and the tendency to experience basic positive emotion and empathy?

Given the small number of studies conducted to date investigating the relationship between prefrontal activity, basic emotions (e.g. happiness, sadness, anger, etc.), and empathic emotion (e.g. *empathic concern, empathic happiness* and *empathic cheerfulness*) in children, the present analysis was designed to investigate the association between the ability to experience empathic emotion in one situation and the ability to experience positive emotion in another situation, in children 6-10 years of age. To this end, empathy and trait contentment scores were used in regression analyses (as independent variables) to examine their association with variation in EEG asymmetry. Change in prefrontal EEG asymmetry in response to a positive stimulus was used as the dependent variable. Each child's behavioral empathy response was measured on an entirely separate day than EEG recording. Since this is strictly a correlational study, the ordering of the variables in the regression is purely arbitrary and implies no significance with respect to cause.

Given that prefrontal EEG asymmetries in particular have been found to relate to the tendency to experience positive emotional/motivational states, we were interested in determining whether different types of empathy (e.g. *empathic concern, empathic happiness* and *empathic cheerfulness*) that involve the generation of some degree of positive emotion (e.g. goodwill), would uniquely correlate with prefrontal EEG asymmetries for two areas of the brain (dorsolateral and frontopolar prefrontal regions) that have been previously implicated in empathic processes in adults. This argument is based on previous work showing a relationship between frontal EEG asymmetry and various emotional/motivational states. There have been two major competing theories of frontal EEG asymmetry: a *valence hypothesis* and a *motivational hypothesis* (Coan & Allen, 2004; Davidson, 2004; Cacioppo, 2004; Harmon-Jones, 2004). The *valence hypothesis* is based on the finding that greater relative right frontal activation was associated with the experience of negative emotion, whereas greater relative left frontal activation is associated with the experience of positive emotion. However, more recent data indicate that greater relative left frontal activity can be associated with anger, an approach-related negative emotion (Harmon-Jones, 2004). More recent conceptualizations of frontal EEG asymmetry (Harmon-Jones, 2004; Davidson, 2004) incorporate these findings, and most researchers agree that frontal asymmetry reflects the activity of an approach-withdrawal motivational system, with greater relative left frontal activation associated with approach related emotions (e.g. anger, exuberance), and greater relative right frontal activity relating to non-approach related emotions (e.g. contentment and sadness) as well as greater withdrawal-related emotions (e.g., fear). Given the frontal EEG asymmetry literature, we hypothesized that individual change in frontal EEG asymmetry produced by a task that generally elicits positive emotion would be associated with individual differences in the type, and intensity, of empathy expressed.

Method

Participants

Families were recruited from state birth records, supplemented by advertising in the local area. Children with major health problems and developmental disabilities were excluded. We did not select for risk for psychopathology. All children included in the EEG analyses were right-handed. One-hundred and twenty eight 6-10 year olds contributed data, but only 108 children were right handed and had usable electrophysiological data (8 six year olds, 25 seven year olds, 42 eight year olds, 27 nine year olds, and 6 ten year olds; *M*=7.92; *SD*=.98). The sample included 56 females, and 105 children were Caucasian, 2 were African American and 1 child was of unspecified ethnicity.

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Procedure

The Laboratory Temperament Assessment Battery (LabTAB; Goldsmith, Reilly, Lemery, Longley & Prescott, 1995) is a standardized set of laboratory episodes designed to elicit different emotional responses, including both negative and positive emotion. Though each child completed a series of labTAB episodes, only the “pop-out toy task” and the “empathy task” were of interest for the purposes of this analysis. The empathy task was completed during a home visit on one day, whereas the pop-out toy task was completed in the laboratory as EEG was recorded simultaneously, on an entirely separate day.

Inducing positive emotion in children—During the “pop-out toy” task (Goldsmith et al., 1995), positive emotion was elicited in children when they played a game with the experimenter and then their parent. A can designed to resemble a can of edible nuts was given to each child. The can actually contained a slinky toy that popped out upon opening the lid. The experimenter opened the can with the child to show them what the can really contained. The child was then given instructions to offer the can to an unsuspecting parent. This sequence of events made up epoch 1-“*game played with experimenter*”. After the experimenter gave the child instructions, the experimenter left the room to go get the parent. The child was left alone in the room with the toy to wait for the parent to enter. This sequence of events made up epoch 2-“*anticipation.*” Finally, the parent entered the room and the child popped the toy with his or her parent. This last series of events made up epoch 3-“*game played with parent.*” The entire episode was video recorded and the child's EEG patterns were recorded during the course of the pop-out toy task.

Each child was scored on how intensely they smiled during the pop-out toy task. This score was labeled “*intensity of smiling.*” The scoring system is based on previous work on the topic (Goldsmith et al., 1995; Pfeifer et al., 2002). For example, a previously published study found that positive affect ratings assigned to each child during the pop-out toy task correlated positively with the amount of positive affect displays (e.g. smiling and laughter) exhibited by the same children during the course of other Laboratory Temperament Assessment Battery (LabTAB) episodes that were also designed to assess positive emotional reactivity (Pfeifer et al., 2002).

The coding system is largely based on the display of facial signs of positive emotion (e.g. Duchenne smiling versus non-Duchenne smiling), which was rated for each child by trained research assistants who viewed the video taped session. The *intensity of smiling* score was used to determine whether participation in the pop-out toy task actually resulted in increased positive emotion. Each child was given a score ranging from 0-3 for the period just before, and after, the task. Additionally, a score was given for each epoch of the task. A 0 score indicated that the child did not smile at all, and 3 indicated that the child exhibited full Duchenne smiles with or without laughter. The inter-rater reliability was high for this measure, with a kappa value of .72.

This task was not designed to be a theory-of-mind task. From the outset, our use of this task was to induce positive emotion. This task could have been used as a theory-of-mind task if we were conducting it with children under the age of 4. Given that our youngest child was 6-years-old, and previous empirical work suggests that typically developing children pass first and second order false-belief tasks by the age of 5 with no difficulty (Frith & Frith, 2003), we were confident that all of the children included in our analysis had already acquired a functional theory-of-mind. In sum, we believe that the pop-out toy task does presuppose a theory-of-mind, but given that we used a typically developing sample of children who were no younger than 6 years old, we felt confident that all children tested understood that their parent did not know what the can actually contained.

Inducing empathy in children—The empathy task, adapted from Zahn-Waxler et al. (1992a), involved the experimenter simulating pain for 30 seconds (pain simulation period) followed by 30 seconds of simulated happiness (relief period). The task started with the experimenter pretending to catch his/her finger in a clipboard and concluded with the experimenter endorsing feelings of happiness. Vocal, bodily and facial indicators were used to rate children on *empathic concern*, *empathic happiness* and *empathic cheerfulness* (see appendix: We developed a new coding system for quantifying empathic behaviors in children aged 6 to 10 years based on previous empirical work by Zahn-Waxler and colleagues (Zahn-Waxler, et al., 1992a; 1992b) with younger children. This system is rooted in the analysis of facial expression, vocal tone and body language. We calculated a weighted kappa value for each variable—*empathic concern*, *empathic happiness* and *empathic cheerfulness*—in order to determine how reliable our measurements were, given that multiple coders were involved with the study).

Empathic concern was operationalized as the amount of concern exhibited facially, vocally, or bodily by the child in response to the negative emotional state of the experimenter during the pain simulation period. *Empathic concern* scores were assigned according to the extent to which the child: exhibited facial signs of concern, made vocalizations that conveyed concern, and/or made bodily gestures that conveyed concern. *Empathic cheerfulness and empathic happiness* were operationalized as the net sum of vocal, bodily, and facial indicators of: (1) a desire to improve the experimenter's emotional state during the pain simulation period (i.e. *empathic cheerfulness*) or; (2) pleasure when the experimenter expressed positive emotion and relief from pain (i.e. *empathic happiness). Empathic happiness* and *empathic cheerfulness* scores were assigned according to the extent to which the child expressed positive emotion by: smiling, making positive vocalizations, and/or making positive body gestures. *Empathic concern*, *empathic happiness* and *empathic cheerfulness* scores ranged from 1 (empathic emotion absent) to 4 (substantial empathic emotion demonstrated). There were 7 levels of ratings for each of the three empathy variables (*empathic cheerfulness*, *empathic happiness* and *empathic concern*) because we coded on .5 increments: 1, 1.5, 2, 2.5, 3, 3.5 & 4 (see Appendix). Kappa values were calculated in the same way for each of the three variables. Inter-rater reliability was estimated by having two graduate students watch the videotapes of 50 children and independently rate each child on *empathic concern*, *empathic happiness* and *empathic cheerfulness.* Weighted kappa values (Cohen, 1968) were calculated for *empathic concern*, *empathic cheerfulness* and *empathic happiness*. The weighted kappa value was .79 for *empathic happiness*, .85 for *empathic cheerfulness*, and .87 for *empathic concern*.

Parent-Report Measures—The parents of each child completed the Child Behavior Questionnaire (CBQ; Rothbart, Ahadi & Hershey, 1994; Rothbart, Ahadi, Hersey & Fisher, 2001). The *low intensity pleasure* scale on the CBQ measures the child's tendency to experience enjoyment in situations involving low intensity, non-risky stimuli (e.g. "[The child] enjoys being read to"). This subscale was included in this analysis in conjunction with the neurophysiological and observational data as an additional measure of the child's ability to experience positive emotion. For each child, mother and father scores were averaged to arrive at one parent-reported *low intensity pleasure* score for each child. Scores on the *low intensity pleasure* scale ranged from 1(extremely untrue of the child) to 7 (extremely true of the child).

EEG Acquisition & Analysis—EEG was recorded from 29 sites (13 homologous pairs and 3 midline sites) using a stretch Lycra cap during the pop-out toy task based on the 10-20 electrode system. EEG was sampled at a rate of 200 per second. (The present analysis is limited to sites that span the frontopolar scalp region—Fp2/1—and the dorsolateral scalp region—F8/7—because our interest was in elucidating the role that the prefrontal cortex plays in the association between empathic emotion, positive emotion, and prefrontal EEG asymmetry, during a task that elicits positive emotion. Activity in all other regions of the prefrontal cortex was not significantly related to empathy scores. EEG asymmetry scores from the identical time points in the parietal region—P3/P4—were used to determine the specificity of our findings to the prefrontal region).

Prior to the onset of "game played with experimenter" (epoch 1), eight 1-minute trials of resting EEG data referenced on-line to physically linked ears (gain=20K) was recorded, four with eyes open and four with eyes closed, in one of two counterbalanced orders. EEG electrode impedances were less than 5KΩ during the baseline EEG recordings and during the task.

EEG recorded during the pop-out toy task was synchronized across subjects based on specific verbal statements made by the experimenter during the task. Specifically, trial onset coincided with a specific experimenter instruction while trial offset occurred after the child opened the toy with their parent. The fact that EEG was recorded while the child was engaged in a task rather than *only* during a resting state is a novel feature of this study. We were interested in studying how prefrontal brain asymmetry behaves during an active task that requires active mental activity. It can be argued that the resting baseline EEG metric is somewhat limited in its ecological validity, and quantifying task-elicited changes in EEG asymmetry—as we have done in this paper—may yield important additional information about the role of frontal EEG asymmetries in emotional expression that the baseline EEG measures cannot. We were very cognizant of the fact that recording EEG during a task introduces more artifact into the data and we were careful to do everything possible to remove it from our data. Therefore, in the next section we present a detailed description regarding the removal of muscle artifact given that EEG was recorded while the child was engaged in a task.

Muscle artifact was removed using a low pass filter of 200 Hz. Then the data from each participant was inspected by an experienced research assistant and additional periods confounded by motion artifact were removed.

Across all children, the average length of "game played with experimenter"=38.39 seconds. On average, 75% (*SD*=26%) of the dorsolateral, 70% (*SD*=29%) of the frontopolar, and 84% (*SD*=21%) of the parietal 1-second units that made up "game played with experimenter" were usable. The average length of "anticipation"=44.11 seconds. On average, 77% (*SD*=27%) of the dorsolateral, 73% (*SD*=27%) of frontopolar, and 86% (*SD*=20%) of the parietal 1-second units that made up "anticipation" were usable. The average length of "game played with parent"=25.45 seconds. On average, 62% (*SD*=29%) of the dorsolateral, 61% (*SD*=28%) of frontopolar, and 74% (*SD*=24%) of the parietal 1-second units that made up "game played with parent" were usable. The amount of usable data did not vary by age, empathy level or *low intensity pleasure score* (see Table 2).

Alpha (8–13 Hz) power values were computed for the dorsolateral (F7/8), frontopolar (Fp1/2) and parietal (P3/4) sites. The power values calculated were based on all of the artifact-free, 1-second units of EEG data (described above) using an off-line whole-head average reference and a fast Hartley transform. We used the 8-12Hz frequency band because, on average, children tend to exhibit reliable EEG activity at a frequency of 8 Hz by the time they are two- years-old, which reaches an average maximum of about 10 Hz by the time the child is ten-years-old (Niedermeyer, 1997; Davidson, Jackson & Larsen, 2000). Therefore, given that the bulk of the sample consisted of 7-9 year-olds, we felt that the frequency band of 8-13 Hz was adequate because it is likely that the vast majority of these children exhibit adult-like patterns of alpha activity by this stage of development.

Decreases in alpha power have been hypothesized to reflect increased cortical activation. Several recent studies involved the recording of EEG and Positron Emission Tomography (PET) simultaneously, and the results indicate that alpha power and glucose metabolism are inversely correlated (Oakes, Pizzagalli, Hendrick, Horras, Larson, Abercrombie, Schaefer, Koger, Davidson, 2004). Furthermore, the EEG asymmetry score is formed by subtracting the log transformed alpha power score from the left electrode site from the log transformed alpha power score from the right electrode site. A higher asymmetry score indicates greater relative left-sided activation.

Statistical Approach—Hierarchical growth curve modeling (HLM 6.02, Scientific Software International, Inc., 2005) was used to chart second by second dorsolateral and frontopolar EEG asymmetry patterning *during* the pop-out toy task. Hierarchical growth curve modeling is a type of multilevel analysis. Our level 1 model estimated the association between prefrontal EEG asymmetry and time elapsed in the pop-out toy task. The individual, second by second EEG asymmetry scores across each of the three epochs of the pop-out toy task were used in the level 1 model. Our level 2 model introduced empathy and contentment variables to explain individual differences in prefrontal EEG asymmetry. A nonlinear model was built because changes in brain electrical activity do not conform to a linear pattern across time (Coan & Allen, 2004). Therefore, the simplest nonlinear model—a quadratic model—was created to accommodate the nonlinearity of EEG asymmetry patterns over time. Each within-epoch quadratic function was treated as a random factor. The linear term embedded in the quadratic function was treated as a random factor. Therefore, the linear slope was allowed to vary between subjects. The linear term determines the basic slope that runs its course from the onset (i.e. the beginning of "toy popped with experimenter") to the offset (i.e. the end of "toy popped with parent") of the pop-out toy task. Thus, the linear term forms the backbone of the EEG asymmetry trajectory during the pop-out toy task. Each quadratic term represents an acceleration parameter that accounts for non-linear change in the shape of the EEG asymmetry trajectory within epoch. The EEG asymmetry trajectory from onset to offset of the pop-out toy task can be viewed as a compilation of three quadratic functions that correspond to the three epochs of the pop-out toy task (These functions were created such that the end point of "game played with experimenter" was mathematically set equal to the start point of "anticipation." This enabled us to graph a continuous, non-saltatory trajectory across time). Each quadratic term was treated as random, to allow for the possibility that EEG asymmetry trajectory might vary between children. Each quadratic term charts the positive or negative acceleration of EEG asymmetry during each of the three pop-out toy epochs. The quadratic term determines the degree to which the trajectory will be curved. The intercept was treated as a fixed factor in order to maximize our ability to discern task-dependent changes in trajectory between children.

At level-1, the EEG asymmetry trajectory during each epoch was characterized as follows:

(1) Dorsolateral/frontopolar EEG asymmetry score at time "x" of "game played with experimenter"= P_0 + P_1(time elapsed from the onset of "game played with experimenter") + P_2(time elapsed in "game played with experimenter")^2 + error.

(2) Dorsolateral/frontopolar EEG asymmetry score at time "y" of "anticipation"= P_0 + P_1(time elapsed from the onset of "game played with experimenter") + P_2(total time in "game played with experimenter")^2 + P_3(time elapsed in "anticipation")^2 + error.

(3) Dorsolateral/frontopolar EEG asymmetry score at time "z" of "game played with parent"= P_0 + P_1(time elapsed from the onset of "game played with experimenter") P_2(total time in "game played with experimenter")^2 + P_3(total time in "anticipation")^2 + P_4(time elapsed in "game played with parent)^2 + error.

The level-2 model was built to explain individual differences in EEG asymmetry trajectory. The level-2 model introduced low intensity pleasure, empathic concern, empathic happiness and *empathic cheerfulness* scores to explain individual differences in the shape of the dorsolateral and frontopolar EEG asymmetry trajectories. Thus, the low intensity pleasure, empathic concern, empathic happiness and *empathic cheerfulness* scores were entered as predictors of P_0, P_1, P_3 and P_4. Neither the empathy variables nor the *low intensity pleasure* scores were combined with EEG data. Rather, *low intensity pleasure* scores and empathy scores (i.e. *empathic concern*, *empathic happiness* and *empathic cheerfulness* scores) were used as independent variables.

Given that *empathic concern, empathic happiness* and *empathic cheerfulness* are positively correlated, *empathic concern, empathic happiness* and *empathic cheerfulness* scores were all entered as independent variables of prefrontal EEG asymmetry intercept and prefrontal EEG asymmetry trajectory during epoch 1-3 of the pop-out toy task in order to determine the independent association between each empathy variable above and beyond the other variables. In sum, the growth curve model uses a best-fit approach. Our inclusion of each empathy variable and the contentment variable was hypothesis driven based on prior work showing that the prefrontal cortex becomes active during empathic processes (e.g. Fan & Han, 2008) *and* during positive emotional states (e.g. Gable & Harmon-Jones, 2008). Specifically, given the known relationship between frontal EEG asymmetry and emotional expression (Davidson, 2004), we were interested in determining if each of the three different behaviorally validated forms of empathy (i.e. *empathic concern, empathic, cheerfulness*, and *empathic happiness*)—in addition to our contentment variable (i.e. *low intensity pleasure*)—would uniquely and/or differentially correlate with second-by-second changes in frontal EEG asymmetry. Fitting a growth curve model to our data enabled us to answer this question. When many independent variables are entered into the growth curve model, each single test of the effect of that predictor (i.e. empathic concern, empathic happiness, empathic cheerfulness, or *low intensity pleasure*) on the dependent variable (i.e. frontal EEG asymmetry) controls for all other effects in the model (Snijders & Bosker, 1999). Thus, with this method, for example, we are able to say that the relationship between *empathic happiness* and frontal EEG asymmetry accounts for unique variance above and beyond any variance accounted for by the relationship between (1) empathic *concern* and frontal EEG asymmetry, and (2) *empathic cheerfulness* and frontal EEG asymmetry. In sum, each independent variable entered into the model served as a covariate for each other independent variable included in the model.

As a statistical comparison to our prefrontal HLM model, the same multilevel model built for the dorsolateral/frontopolar EEG asymmetry data was applied to the parietal (P3/4) EEG asymmetry data. This was done to determine whether *low intensity pleasure* and/or empathy scores would predict parietal EEG asymmetry trajectory. If *low intensity pleasure* and/or empathy scores predict parietal EEG asymmetry trajectory <u>and</u> prefrontal EEG asymmetry trajectory in the same way, this would be evidence for a more global brain-empathy effect, not a unique prefrontal-empathy effect.

To determine how the neurophysiological profiles of children who exhibit different amounts of *empathic concern*, *empathic happiness* or *empathic cheerfulness* differ, a high, moderate and low group were created. Empathy scores ranged from 1 (the trait is absent) to 4 (the trait is present to a substantial degree). Children in each of the three “high” empathy groups had a empathy score of 3 or greater; children in each of the three “moderate” empathy groups had a empathy score equal to or greater than 1.5 but less than 3; and children in the “low” empathy groups had a empathy score lower than 1.5. Importantly, because *empathic concern, empathic happiness* and *empathic cheerfulness* are positively correlated variables, the graphs of EEG asymmetry trajectory for each group should not be thought of as a depiction of how prefrontal EEG asymmetry would change over time for children who exhibited different levels of each empathy variable with the other variables statistically removed.

Results

Behavioral Results

Did the pop-out toy task elicit positive emotion?—Across the sample as a whole, *intensity of smiling* during "game played with parent" (i.e. epoch 3 of the pop-out toy task) was significantly higher (M=2.52; SD=.73) than *intensity of smiling* just before the onset of the task (i.e. "game played with experimenter"), M=1.64, SD=.84, p<.001. This indicates that there was a significant increase in positive emotion over the course of the pop-out toy task.

How do the different forms of empathy relate to each other?—Across all children, the mean *empathic concern* score was 1.99 (SD=.70); the mean *empathic cheerfulness* score was 1.55 (SD=.71); and the mean *empathic happiness* score was 2.03 (SD=.98). *Empathic concern, empathic cheerfulness*, and *empathic happiness* correlate positively (correlations ranged from .30 to .53; all *p*s<.01; see Table 3). These moderate correlations suggest that each of these empathy variables contain some independent variance.

Developmental analyses—The sample included 53 girls, 8 six-year-olds, 22 seven-year-olds, 44 eight-year-olds, 24 nine-year-olds, and 5 ten-year-olds (*M* age=7.96; *SD*=.98). Although the age distribution was uneven, we nevertheless examined correlations between age contentment, and the empathy variables (see Table 4). Across the sample as a whole, age was not associated with any of the empathy variables or contentment (all *p*s>.1). There was a significant gender effect. Similar to previous findings (Zahn-Waxler, 2000), girls tended to earn higher empathy scores than boys (see Table 4). Furthermore, girls tended to score higher on contentment (see table 4).

In addition, as an additional means to investigate whether there were age related differences in empathy and positive affect responding, the sample was clustered into two age groups; one group contained all children aged 6 to 8 years old and the other group contained children aged 9 to 10 years old. The two groups did not differ on any of the empathy variables (i.e. *empathic concern, empathic cheerfulness*, or *empathic happiness*) or contentment (all *p*s>.29). Furthermore, when the same analyses were performed with the sample broken into a group containing 6 and 7 year olds and a second group containing 8, 9 and 10 year olds, no significant differences emerged (all *p*s>.18).

Physiological Results

Baseline EEG data—Baseline dorsolateral and frontopolar EEG activity—recorded before the pop-out toy task began—did not predict *empathy or low intensity pleasure* scores.

Dorsolateral EEG asymmetry during the task—The dorsolateral (F8/7) second-by-second electroencephalographic data from each child was used as the level 1 outcome variable (Table 5). Empathic concern, empathic cheerfulness, empathic happiness, and *low intensity pleasure* (i.e. contentment) scores were used as level 2 variables to examine associations with dorsolateral EEG asymmetry trajectory during each epoch of the pop-out toy task (Table 5). ß coefficients represent per second changes in EEG asymmetry. From the beginning of "game played with experimenter" (epoch 1) to the end of "game played with parent" (epoch 3), significant change occurred in dorsolateral EEG asymmetry across children. This is demonstrated by the fact that dorsolateral EEG asymmetry at the onset of "game played with experimenter" differed significantly from dorsolateral EEG asymmetry at the offset of "game played with parent" (p<.01).

Empathic cheerfulness was associated with increasing relative right-sided activation in dorsolateral EEG asymmetry during "game played with parent" ($ß=-7.3\times10^{-5}$; p<.05; Table

5). *Empathic happiness* related to increasing relative left-sided activation in dorsolateral EEG asymmetry during “game played with parent” (ß=6.7×10^{-5}; $p<.05$; Table 5). Given that all 3 of our empathy variables were entered as predictors of dorsolateral EEG asymmetry intercept and dorsolateral EEG asymmetry during epoch 1-3 of the task, the significant effects described above indicate that *empathic happiness* and *empathic cheerfulness* were the only empathy variables that accounted for unique variance in dorsolateral EEG asymmetry above and beyond the other independent variables.

Summary of dorsolateral findings—*Empathic cheerfulness* is associated with increased right-sided activity in the dorsolateral scalp region during a positive task, whereas *empathic happiness* is associated with increased left-sided activity. *Empathic concern* did not relate to change in dorsolateral EEG asymmetry over the course of the task.

Frontopolar EEG asymmetry during the task—Frontopolar (Fp2/1) second-by-second electroencephalographic data from each child was used as the level 1 outcome variable (Table 6). Empathic concern, empathic happiness, empathic cheerfulness, and *low intensity pleasure* (i.e. contentment) scores were used as level 2 variables in the model (Table 6). ß coefficients represent per second changes in frontopolar EEG asymmetry. Frontopolar EEG asymmetry at the onset of pop-out toy differed significantly from frontopolar EEG asymmetry at the offset of the pop-out toy task ($p<.01$).

Low intensity pleasure was associated with an overall increase in relative left-sided activity (ß=1.8×10^{-3}; $p<.05$; Table 6). *Empathic concern* was associated with increasing relative right-sided activation in the frontopolar region during “game played with experimenter” (ß=-4.3×10^{-5}; $p<.05$; Table 6). *Empathic cheerfulness* was associated with increasing relative right-sided activation in frontopolar EEG asymmetry during “game played with experimenter” (ß=-5.8×10^{-5}; $p<.05$; Table 6). The significant effects described above indicate that *low intensity pleasure, empathic concern* and *empathic cheerfulness* account for unique variance in frontopolar EEG asymmetry above and beyond the other independent variables included in the model.

Summary of frontopolar findings—*Empathic cheerfulness* and *empathic concern* were associated with increased relative right sided activity in the frontopolar scalp region during the task, whereas contentment was associated with increased left-sided activity during the task. *Empathic happiness* did not relate to change in frontopolar EEG asymmetry.

Parietal EEG asymmetry—The level-1 and level-2 models that were combined and applied to the dorsolateral and frontopolar EEG asymmetry data were also applied to the parietal EEG asymmetry data. *Empathic cheerfulness* was positively associated with parietal EEG asymmetry intercept value (ß=3.2×10^{-2}; $p<.05$), but not *empathic concern* or *empathic happiness*. *Empathic concern*, *empathic happiness* and *low intensity pleasure* were not associated with parietal EEG asymmetry intercept value or change in parietal EEG asymmetry during epoch 1, epoch 2, or epoch 3 (all *p*s>.05). These results suggest that the observed relationship between empathic emotion and change in dorsolateral and frontopolar EEG asymmetry during the pop-out toy task is predominantly unique to the prefrontal region.

Distinguishing the neurophysiological patterns of children who demonstrate substantial empathic concern, empathic happiness, or empathic cheerfulness from children who do not—Children who demonstrate *empathic concern, empathic happiness* or *empathic cheerfulness* can be distinguished—based on the pattern of prefrontal brain asymmetry they exhibit during a positive stimulus—from children who do not demonstrate empathy. Table 7 summarizes the patterns of prefrontal EEG asymmetry that characterize children who demonstrated considerable *empathic concern*, *empathic happiness,* or *empathic cheerfulness*.

Empathic concern—Children in the high *empathic concern* group exhibited greater relative right dorsolateral activity at the onset of the pop-out toy task relative to children who exhibited less *empathic concern* (p<.01; Figure 1). Simultaneously, these children exhibited symmetrical frontopolar activity at the onset of the pop-out toy task relative to children who exhibited less *empathic concern* (p<.01; Figure 1).

Importantly, children in the high *empathic concern* group exhibited a shift from right to left dorsolateral and frontopolar activity over the course of the pop-out toy task, showing significantly more left dorsolateral and more left frontopolar activity during “game played with parent” (epoch 3) relative to children who exhibited less *empathic concern* during the empathy task (*p*s<.01; Figure 1).

Empathic happiness—Children in the high *empathic happiness* group exhibited symmetrical dorsolateral and frontopolar activity at the onset of the pop-out toy task relative to children who exhibited less *empathic happiness* (*p*s<.05; Figure 2).

However, these children exhibited a shift from symmetrical to left dorsolateral activation over the course of the pop-out toy task, showing significantly more left dorsolateral activity during “game played with parent” (epoch 3) relative to children who exhibited less *empathic happiness* during the empathy task (p<.05; Figure 2).

Children in the high *empathic happiness* group did not exhibit much of a shift away from symmetrical frontopolar activity over the course of the pop-out toy task.

Empathic cheerfulness—The dorsolateral EEG asymmetry trajectory of children in the high *empathic cheerfulness* group did not differ from children in the other *empathic cheerfulness* groups *(*p>.05; Figure 3). In contrast, children in the high *empathic cheerfulness* group showed a striking increase in left frontopolar activity over the course of the pop-out toy task relative to children in the other two *empathic cheerfulness* groups (p<.05; Figure 3).

Summary—Figure 4 provides an overall picture of how the prefrontal cortex behaves during a positive affect inducing task in children who exhibit an ample amount of one of the three types of empathy. The activity of the dorsolateral prefrontal cortex and the frontopolar prefrontal cortex are plotted together. Children who exhibit a great deal of *empathic concern* exhibit both right and left prefrontal activity during a positive task. Children who exhibit large amounts of *empathic happiness* tend to exhibit symmetrical prefrontal activity until the very end of the task. Lastly, children who exhibit an abundant amount of *empathic cheerfulness* exhibit an overall left-sided pattern of prefrontal activity, with particularly potent left-sided frontopolar activity.

Discussion

Our findings provide novel evidence that shows for the first time that changes in prefrontal brain electrical asymmetries during a positive incentive in children are related to behavioral measures of empathy obtained during a separate experimental session.

Children who demonstrated high *empathic concern* during the empathy task activated first the right *and then* the left prefrontal cortex during the pop-out task. The ability to flexibly shift between patterns of prefrontal activation asymmetry may be associated with a shift toward a more exuberant positive emotional state during the task. Furthermore, a child's ability to flexibly shift between negative and positive emotional states based upon contextual information may provide an optimal substrate for the expression of certain forms of empathy (e.g. *empathic concern*) that call for the generation of a combination of positive (i.e. feelings of goodwill) and negative (i.e. sadness) emotion in response to the emotional displays of another person.

Children who demonstrated high *empathic happiness* during the empathy task exhibited relatively symmetrical prefrontal activity during the pop-out toy task, indicating that these children maintained equal amounts of left-sided and right-sided prefrontal activation (i.e. co-activation) during the course of the pop-out toy task. The sustained maintenance of equal amounts of left and right prefrontal cortex activity over the course of a positive stimulus may indicate that these children generally maintain a relatively neutral emotional set-point that may tend to make them particularly willing to (or susceptible to) vicariously absorb the positive emotion exuded by others because they have “emotional space” available to fill.

Children who exhibited high *empathic cheerfulness* during the empathy task demonstrated an ability to exhibit consistent left prefrontal activity during the course of the pop-out toy task. Dual activity in left dorsolateral and left frontopolar cortex may be suggestive of their ability to generate a high level of positive emotion, which can be readily used in an empathic manner. The ability of these children to activate their left dorsolateral and left frontopolar cortex simultaneously during the pop-out toy task may be representative of an enhanced ability to harness positive emotion when exposed to a positive stimulus.

What distinguishes children who exhibit *empathic cheerfulness* from those who do not is their frontopolar activity during a positive task. We found that frontopolar EEG asymmetry relates to empathic emotion (i.e. *empathic concern, empathic happiness* and *empathic cheerfulness) and* basic positive emotion (i.e. *low intensity pleasure*/contentment). This dual association suggests that frontopolar activity may be a neurophysiological correlate of the previously described (Rothbart et al., 1994; Robinson et al., 2001) relationship between our ability to experience basic positive emotions and our ability to experience empathy.

Increased frontopolar activity may enable children to integrate information about their own emotional state with information about the emotional state of another. If a child has a tendency to experience positive emotional states, it is likely that he/she will be in a positive emotional state when he/she is confronted with the emotional displays of others. Being in a positive emotional state may promote the experience of empathy because the empathizer can tap into and utilize those positive emotions in an empathic manner (Staub, 1984). For example, the basic positive emotions (e.g. happiness, contentment, etc.) held by the empathizer may promote the experience of goodwill that is a critical ingredient of the empathic experience. The known role of frontopolar cortex in integrating and organizing higher order, self-generated (internal) information with stimulus-dependent (external) information (Christoff & Gabrieli, 2000; Gusnard, Akbudak, Shulman & Raichle, 2001) may be extremely important for the successful orchestration of a second order (empathic) emotional state that is derived from the dual representation of one's own emotional state and that of the target.

In conclusion, our results support the idea that the dynamic change in scalp-recorded prefrontal activation during a positive stimulus is associated with the tendency to experience empathic emotion. *Empathic happiness* and *empathic cheerfulness* are associated with changes in dorsolateral EEG asymmetry during a positive stimulus. *Low intensity pleasure, empathic concern* and *empathic cheerfulness* are associated with changes in frontopolar EEG asymmetry during a positive stimulus. Empathic emotions may correlate with dorsolateral and frontopolar activity because these regions may be particularly important for our ability to (1) hold and access an internal representation of our own emotional state, (2) create an internal representation of the emotional states of others, and (3) use that information to generate an appropriate positive emotion (e.g. happiness and feelings of goodwill in the case of empathic happiness)—or blend of positive emotion and negative emotion (e.g. sadness and feelings of goodwill in the case of *empathic concern*)—when confronted with the emotional displays of others.

Developmental issues

Our study participants were children, and given the data on links between prefrontal cortical function and empathy in adults, we were interested in determining whether the relationship between prefrontal function and empathy would be present in children. Although none of our behavioral measures varied with age (i.e. empathy did not increase with age), empathy was associated with prefrontal activation in this young group of children. This suggests that not only is prefrontal function important for empathic processes in adults, the prefrontal cortex is associated with empathy processes in children as young as 6 years of age. It will be interesting to investigate whether prefrontal activity is associated with expression of empathy in even younger children. In sum, our data suggest that the relationship between prefrontal function and empathy is observable at a relatively young age.

Additionally, this type of analysis has not been conducted with adults. It will be interesting to test whether a similar pattern of activity would be observed in an adult sample. For example, it will be worthwhile to test whether dynamic shifts in prefrontal activation in adults during a positive incentive are associated with empathic processes as we have found them to be in children. Some promising findings from a recent ERP study with adult participants (Fan & Han, 2008) provide preliminary evidence that the prefrontal cortex *is* similarly recruited during an actual bout of empathy.

Limitations and Future Directions

Electroencephalography represents gross measures recorded from the scalp surface. While the time resolution of such measures is excellent, the spatial resolution is coarse and because of the sparse electrode array we did not attempt to estimate intracerebral sources of the scalp-recorded signals. Our analysis method did take good advantage of the time resolution afforded by this method.

Future studies should focus on elucidating further the distinctive, yet collaborative roles of the frontopolar region and the dorsolateral region in empathic processing. This could be accomplished by recording EEG (or using neuroimaging methods) while empathy is being elicited (e.g. Singer et al., 2004). EEG recorded during a bout of empathy would help to directly delineate the temporal course of neural activity as it relates to empathy. For example, it will be important to see whether a pattern of prefrontal asymmetry trajectory similar to those observed in the present study emerges when EEG is recorded while empathy is induced. In addition, to further unravel the complexity of the different forms of empathy described in this report, it will be necessary to further investigate *empathic happiness* and *empathic cheerfulness* by comparing then rigorously to non-empathic positive emotion. For example, it would be useful to determine in more detail how *empathic happiness* differs neurophysiologically, from happiness per se. Lastly, given the association found between the experience of basic positive emotions (e.g. contentment) and the experience of empathic emotions, it will be interesting to determine how positive emotions held by the empathizer may be used differently to facilitate the expression of *empathic concern* versus *empathic cheerfulness*.

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Appendix

Appendix: The Observational Empathy Coding System

EMPATHIC CONCERN

Empathic concern is judged to be present if the child expresses concern for the experimenter via facial, vocal or bodily means. *Empathic concern* can be coded using .5 increments when necessary (i.e. 1.5, 2.5, and 3.5).

1. Complete absence of concern for victim; or child is indifferent to victim's pain (i.e. sustained neutral emotion is included here).

2. Slight change in expression that includes at least 1 of the following indicators (usually at a low intensity): facial (for example, sobering and/or brow furrow), bodily (tension), or vocal tone changes (e.g. “oh!”). Code an inquiry like, “are you ok?” or a statement like “ouch!” here if the statement *does* demonstrate something more substantial than just a dispassionate query/statement but does *not* demonstrate enough concern to warrant a 3 (i.e. the query provides a slight indication of concern, but is not intense/sympathetic enough to warrant a 3).

3. Moderate concern which may be demonstrated by any one of several indicators: a more pronounced sobering of expression (compared to what a 2 calls for), and/or the presence of a sympathy face in which eyebrows are drawn down and lips are down turned; in addition, concern may be expressed in sympathetic vocal tones (for example, “are you ok?” or “ouch!”), or bodily posture. Note that duration is the primary distinction between 2 and 3 (a 3 *usually* involves a more intense display of concern compared to a 2, but a 3 *always* involves a longer duration of concern than what a code of 2 calls for).

4. Substantial concern demonstrated by any of the following: even fuller recruitment of facial expression in the form of a sympathy face in which eyebrows are drawn down and lips are down turned (i.e. in order for the code of 4 to be warranted, sympathy must be [1]shown in more than one region of the face <u>or</u> [2]must be present for a sustained duration if only present in 1 facial region <u>or</u> [3]if expressed more intermittently, the intensity *must* be strong), presence of sympathetic vocal tones (for example, “are you ok?), or concern indicated by bodily posture. Note that <u>intensity</u> is the primary distinction between a 3 and 4 code, though duration may sometimes be useful for making a distinction between the 3 and 4 code. To warrant a code of 4, the emotion displayed *must be* more intense than what a 3 calls for, though it is not a requirement that the presence of the emotion be longer in duration than a 3 would call for.

EMPATHIC HAPPINESS AND EMPATHIC CHEERFULNESS

Empathic cheerfulness is the degree to which the child responds to the distress of the experimenter by trying to induce positive emotion in the experimenter (i.e. positive emotion expressed by the child that seems to be exuded to facilitate improving the victim's negative emotional state).

Empathic happiness is the degree to which the child responds with positive emotion (demonstrating pleasure) in response to the change in emotion expressed by the experimenter as the experimenter moves from the expression of distress to the expression of positive emotion.

Empathic cheerfulness and empathic happiness can be coded using .5 increments when necessary (i.e. 1.5, 2.5, and 3.5).

1. Absent. Neutral emotion and/or meager smile that comes across as only a simple orienting response is also included here.
2. Slight positive emotion that may only be present for a few seconds that seems to reflect some sort of emotional contagion (i.e. the child expresses emotion in parallel with the experimenter feeling good or the child expresses positive emotion in response to the change in the experimenter's expressed emotion) and/or *pleasure that the experimenter is feeling better* (this type of empathy is only applicable during the relief period) OR slight positive emotion that may only be present for a few seconds that seems to be exhibited to induce a positive (or otherwise improved) emotional state in the experimenter; which may be expressed facially (for example, smiling that is closed mouth), verbally/vocally or bodily.
3. Moderate positive emotion expressed facially (for example, broad closed mouth smiling and/or laughter), verbally/vocally or bodily. The distinction between a 2 and 3 is based on intensity and duration. To warrant a 3, the positive emotion must be greater in intensity than what a 2 calls for (but may not be present very long). That is, give a code of 3 even if the positive emotion is displayed only briefly if it is more intense than what a 2 calls for. You can also give a code of 3 if the duration of the positive emotion/pleasure expressed is for more than a few seconds even if it is not that intense for the entire time that the child is showing evidence of some level of positive emotion.
4. Sustained or high intensity positive emotion expressed facially (for example, broad or open-mouth smiling and/or laughter), verbally/vocally or bodily. The primary difference between a 3 and 4 is intensity and duration (i.e. give a 4 if the child shows high intensity positive emotion—usually a broad and/or opened mouth smile, —-but only briefly. Also, give a code of 4 if the positive emotion expressed is lower in intensity but is present for a significant proportion of the time).

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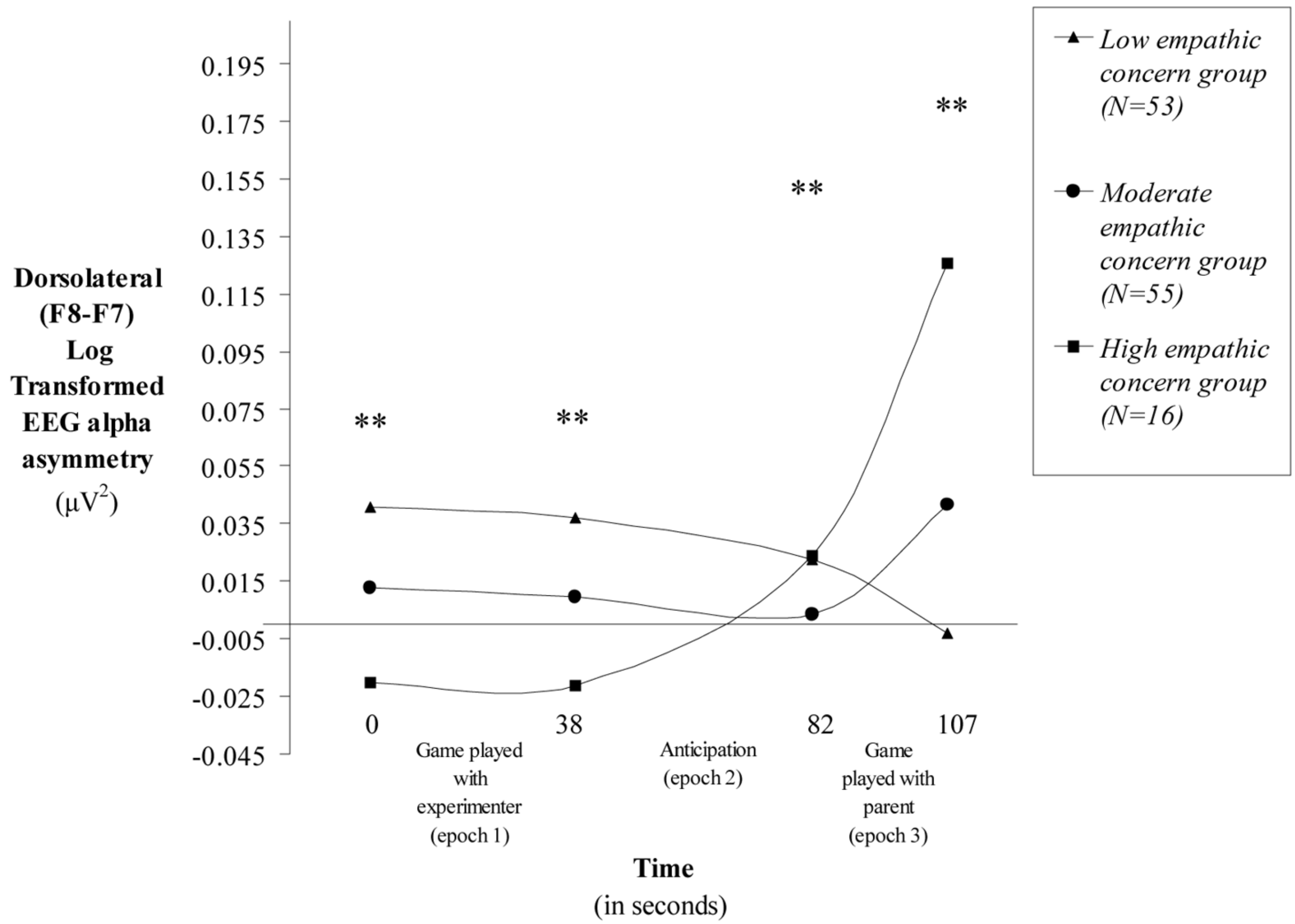


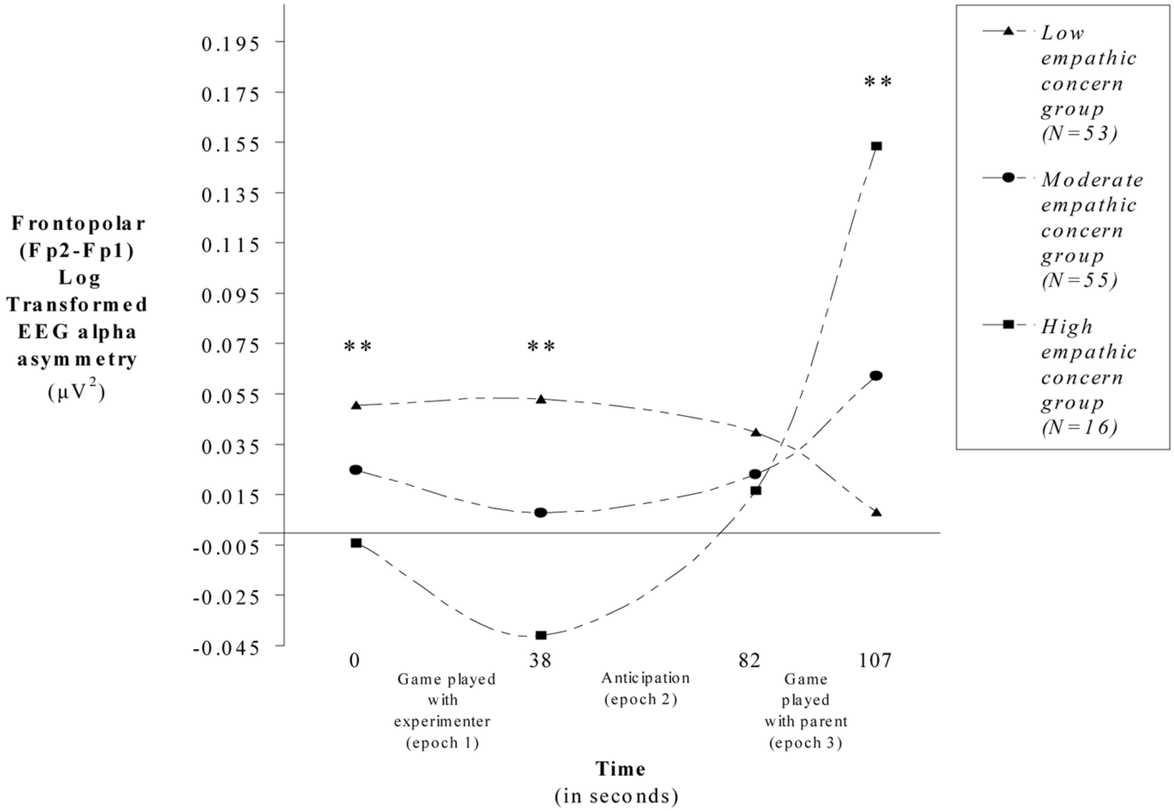
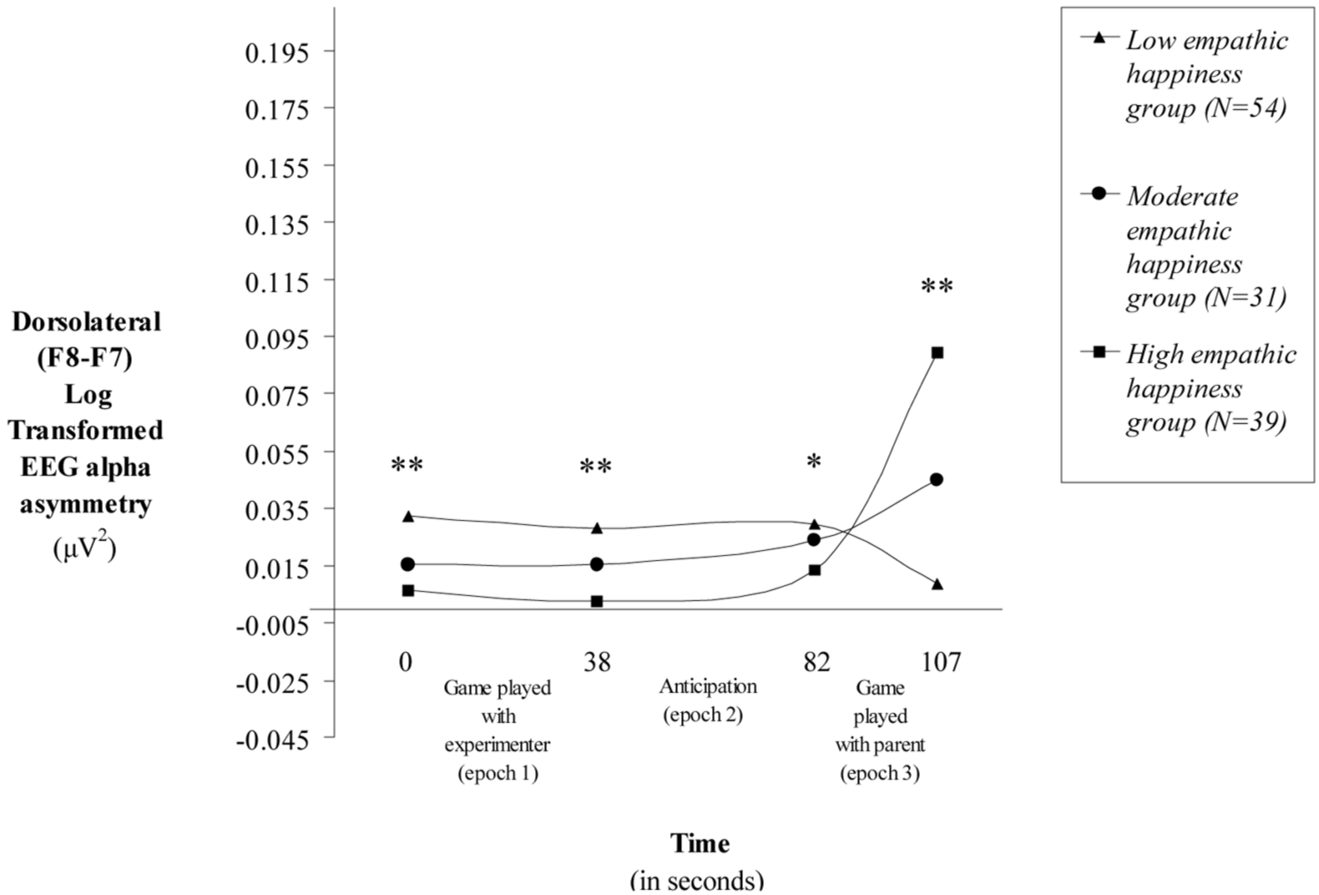


Figure 1.

Dorsolateral and frontopolar EEG asymmetry trajectories during "pop-out toy" for the low, moderate and high *empathic concern* groups. The time scale is based on the average length of the task across all children. Across all children, the average length of "game played with experimenter"=38.39 seconds. The average length of "anticipation"=44.11 seconds. The average length of "game played with parent"=25.45 seconds. *p <.05. **p <.01.


Dorsolateral (F8-F7) Log Transformed EEG alpha asymmetry (μV2)
0.195
0.175
0.155
0.135
0.115
0.095
0.075
0.055
0.035
0.015
-0.005
-0.025
-0.045
**
**
*
**
0
38
82
107
Game played with experimenter (epoch 1)
Anticipation (epoch 2)
Game played with parent (epoch 3)
Time (in seconds)
Low empathic happiness group (N=54)
Moderate empathic happiness group (N=31)
High empathic happiness group (N=39)

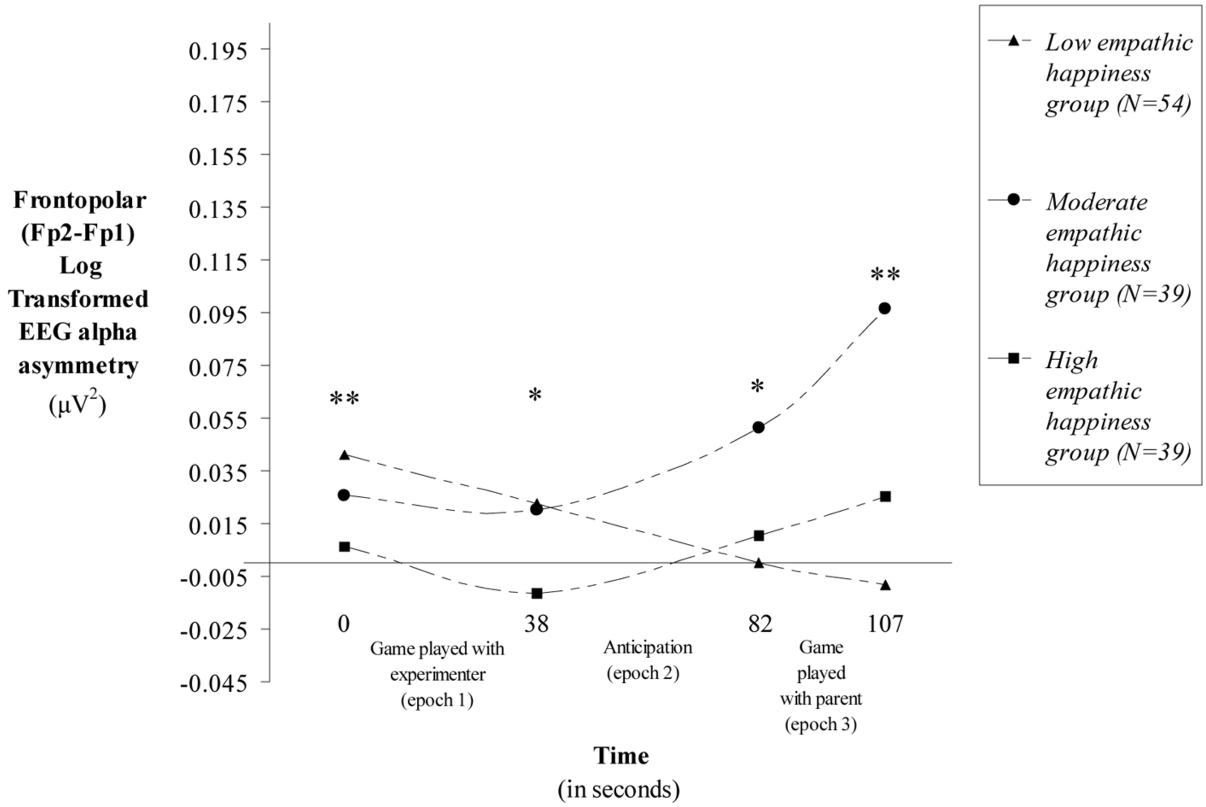
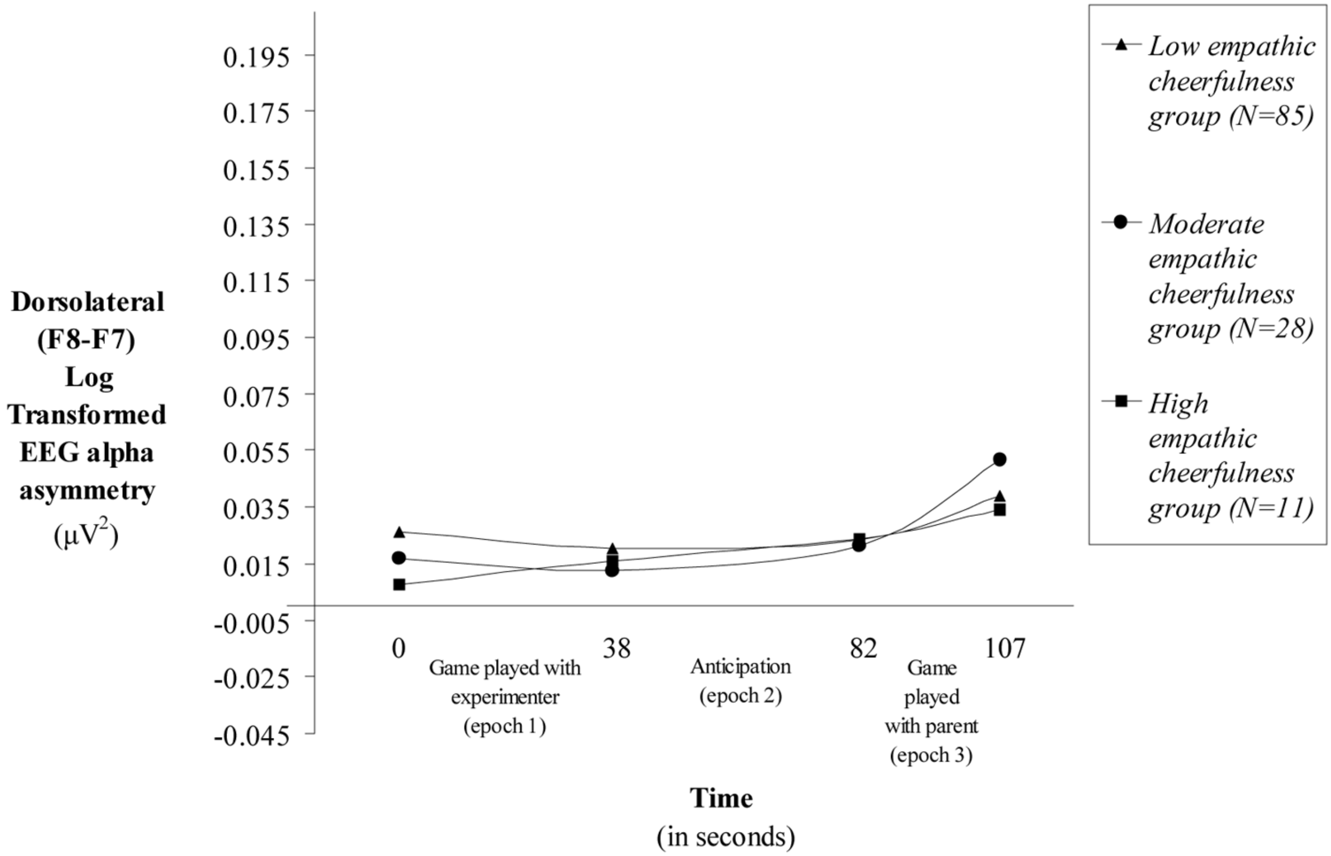


Figure 2.
Dorsolateral and frontopolar EEG asymmetry trajectories during “pop-out toy” for the low, moderate and high *empathic happiness* groups. The time scale is based on the average length of the task across all children. Across all children, the average length of “game played with experimenter”=38.39 seconds. The average length of “anticipation”=44.11 seconds. The average length of “game played with parent”=25.45 seconds. *p <.05. **p <.01.


Dorsolateral (F8-F7) Log Transformed EEG alpha asymmetry (μV²)
0.195
0.175
0.155
0.135
0.115
0.095
0.075
0.055
0.035
0.015
-0.005
-0.025
-0.045
0
38
82
107
Game played with experimenter (epoch 1)
Anticipation (epoch 2)
Game played with parent (epoch 3)
Time
(in seconds)
Low empathic cheerfulness group (N=85)
Moderate empathic cheerfulness group (N=28)
High empathic cheerfulness group (N=11)

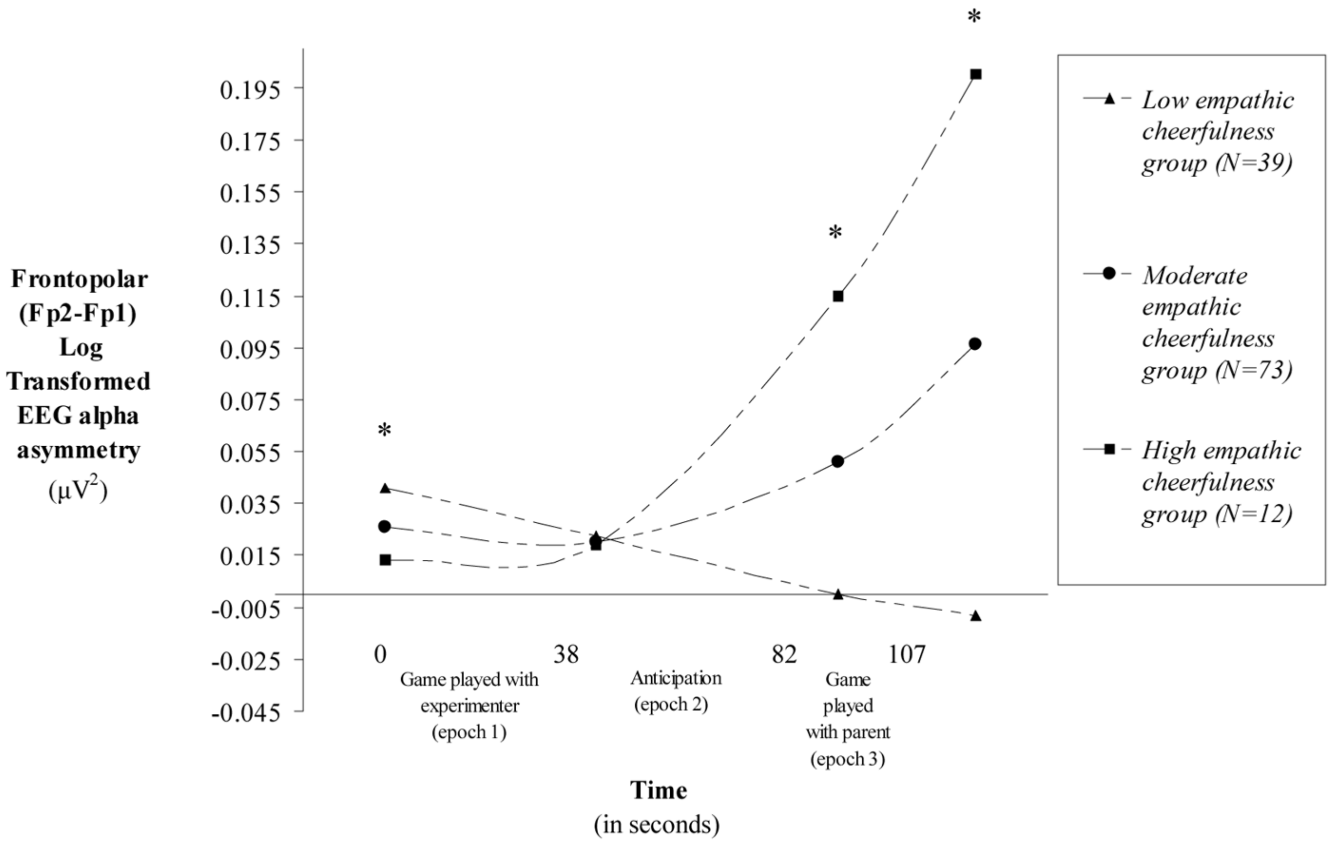
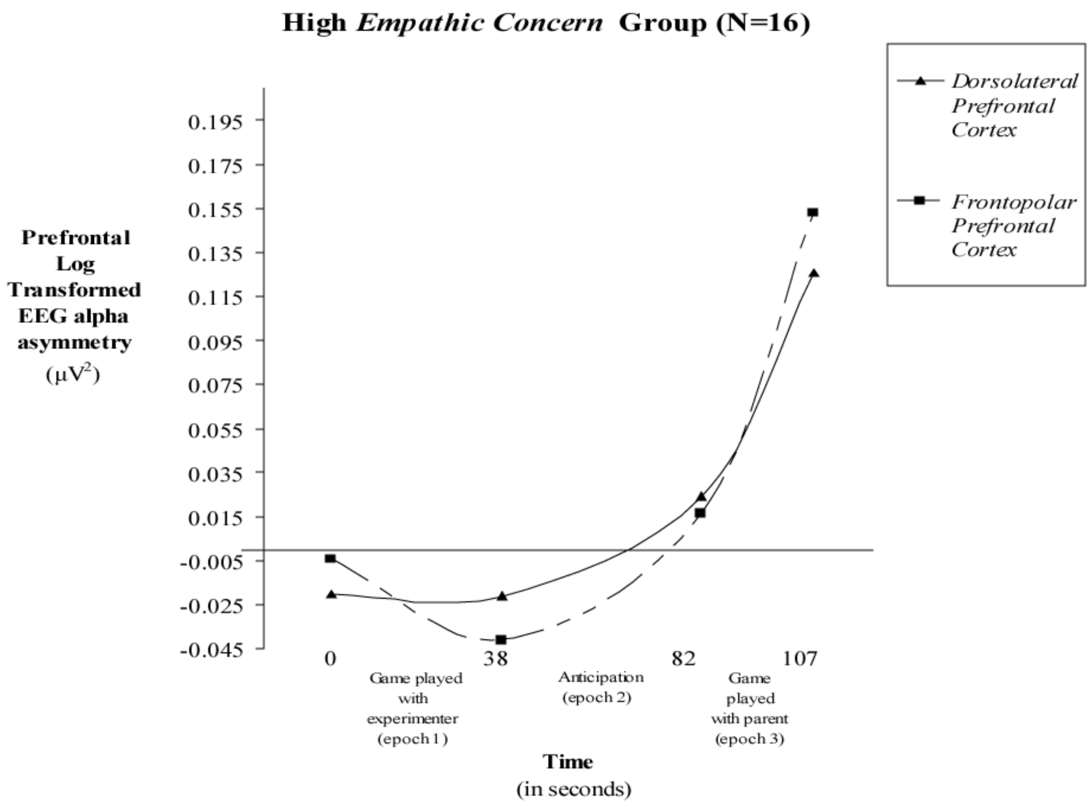
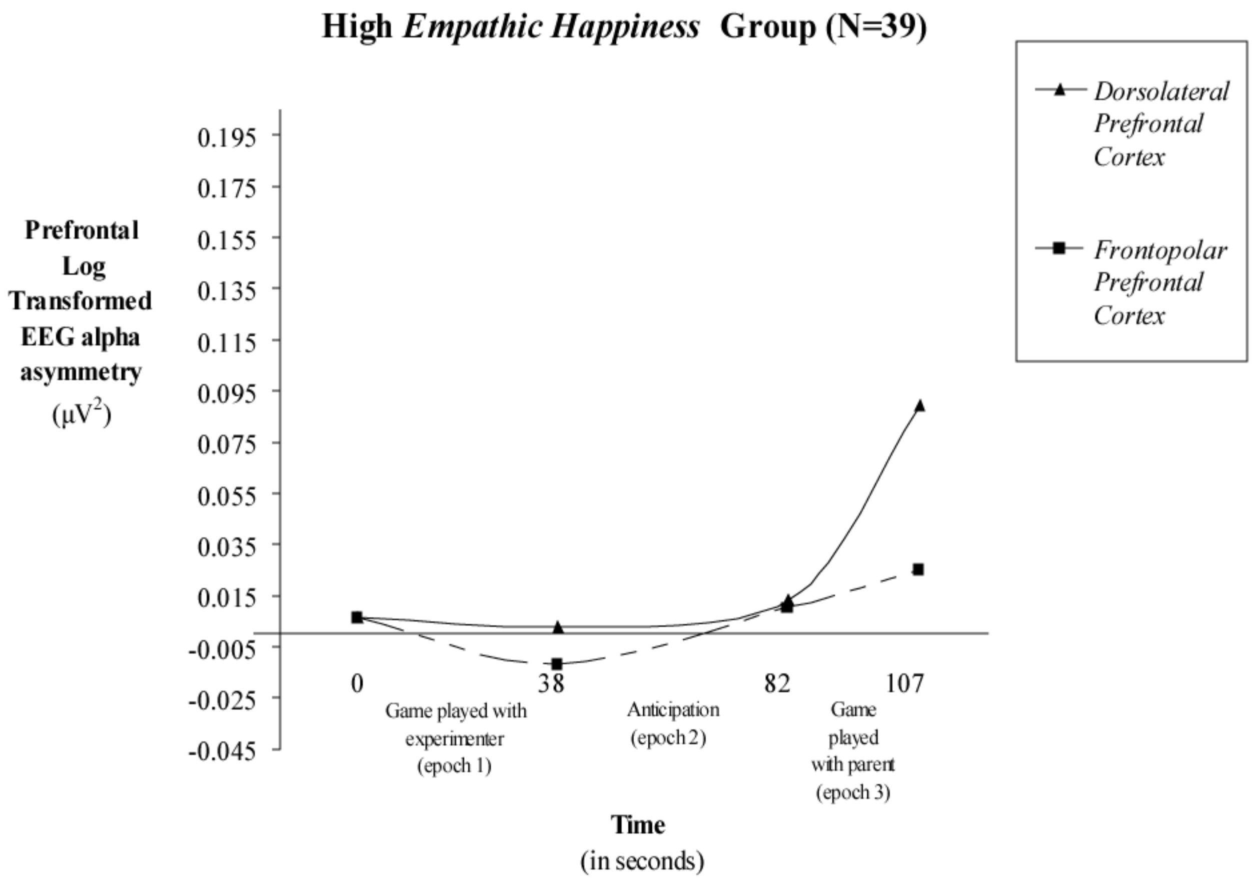


Figure 3.
Dorsolateral and frontopolar EEG asymmetry trajectories during “pop-out toy” for the low, moderate, and high *empathic cheerfulness* groups. The time scale is based on the average length of the task across all children. Across all children, the average length of “game played with experimenter”=38.39 seconds. The average length of “anticipation”=44.11 seconds. The average length of “game played with parent”=25.45 seconds. *p <.05. **p <.01.


High *Empathic Concern* Group (N=16)
Dorsolateral Prefrontal Cortex
Frontopolar Prefrontal Cortex
Prefrontal Log Transformed EEG alpha asymmetry (μV^2)
0.195
0.175
0.155
0.135
0.115
0.095
0.075
0.055
0.035
0.015
-0.005
-0.025
-0.045
0
38
82
107
Game played with experimenter (epoch 1)
Anticipation (epoch 2)
Game played with parent (epoch 3)
Time
(in seconds)


High *Empathic Happiness* Group (N=39)
Dorsolateral Prefrontal Cortex
Frontopolar Prefrontal Cortex
Prefrontal Log Transformed EEG alpha asymmetry (μV2)
0.195
0.175
0.155
0.135
0.115
0.095
0.075
0.055
0.035
0.015
-0.005
-0.025
-0.045
0
38
82
107
Game played with experimenter (epoch 1)
Anticipation (epoch 2)
Game played with parent (epoch 3)
Time
(in seconds)

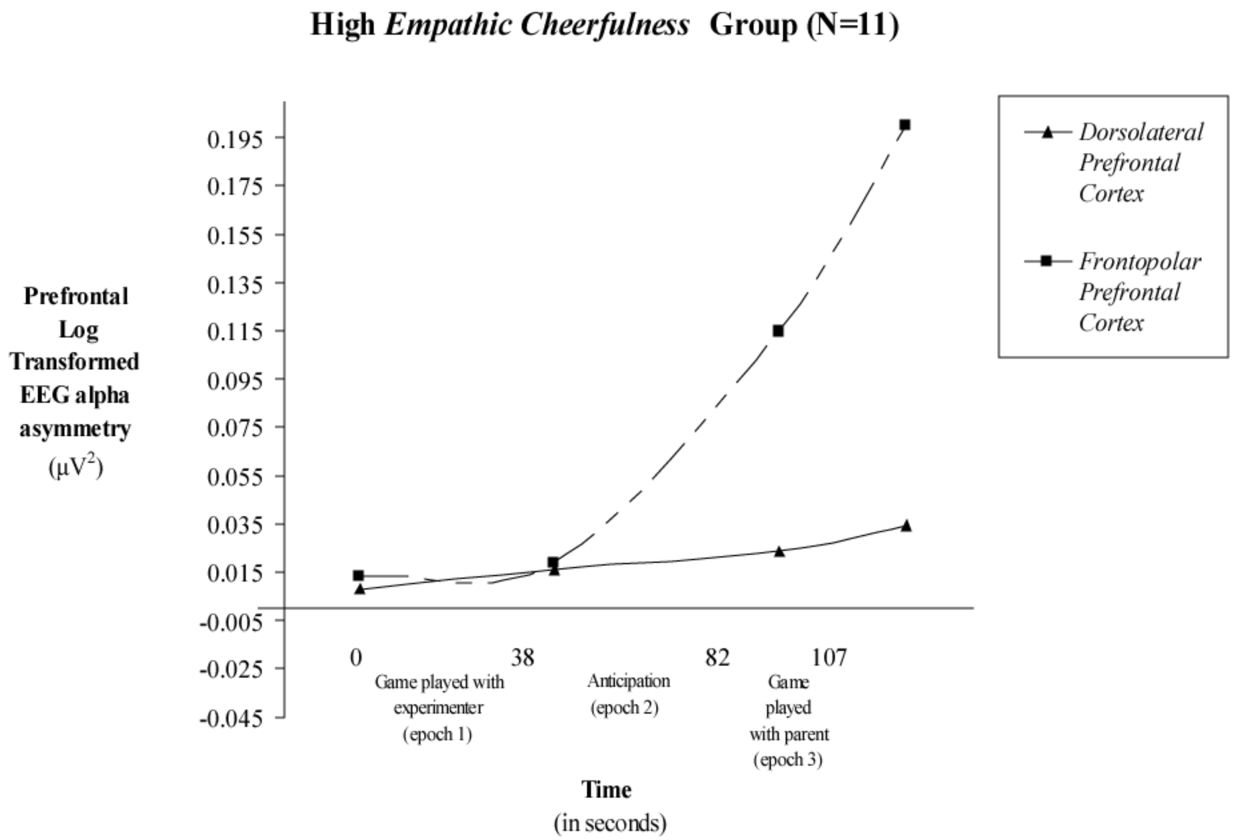


Figure 4.

Prefrontal cortex activity during a positive affect inducing task in children who are highly empathic. The activity of the dorsolateral prefrontal cortex and the frontopolar prefrontal cortex are plotted together for each empathy group.

Table 1

Definitions of Empathy Subtypes

Empathy Subtype	Description
empathic concern	The tendency to vicariously experience feelings of goodwill and concern in response to someone else's pain
empathic cheerfulness	The tendency to exude positive emotion as a means to alleviate the negative emotion that another person is feeling by catalyzing a positive emotional state in that person
empathic happiness	The tendency to vicariously experience feelings of pleasure and goodwill in response to someone else's display of positive emotion

Table 2

Correlation Between Percentage of Usable Data and Behavioral Variables (N=103)

	Age	Empathic concern	Empathic happiness	Empathic cheerfulness	Low intensity pleasure
Percent (%) usable F7/8 data collected during the pop-out toy task	.04 (*p*=.71)	−.11 (*p*=.30)	.06 (*p*=.56)	.03 (*p*=.78)	.10 (*p*=.34)
Percent (%) usable Fp1/2 data collected during the pop-out toy task	.05 (*p*=.66)	−.16 (*p*=.12)	−.10 (*p*=.34)	.001 (*p*=.99)	.18 (*p*=.09)

Note: Values in parentheses represent p values.

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Table 3

Correlation Between Empathy Variables (N=118)

	***Empathic concern* during the pain simulation**	***Empathic cheerfulness* during the pain simulation**	***Empathic happiness* during the relief period**
Empathic concern during the pain simulation	---		
Empathic cheerfulness during the pain simulation	.30**	---	
Empathic happiness during the relief period	.38***	.53***	---

Note: Values in parentheses represent p values.

** p <.01.

*** p <.001

Table 4

Correlation Between Empathy and Age and Gender (N=118)

	Age	**Gender**
Empathic concern during the pain simulation	−.06 (*p*=.60)	−.21* (*p*<.05)
Empathic cheerfulness during the pain simulation	.13 (*p*=.20)	−.35* (*p*<.01)
Empathic happiness during the relief period	.17 (*p*=.10)	−.24* (*p*<.05)
Low Intensity Pleasure (Child Behavior Questionnaire)	−.15 (p=.68)	−.27* (p<.05)

Note: Values in parentheses represent p values.

*p <.05.

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Table 5

Hierarchical EEG Asymmetry Model for Dorsolateral Prefrontal Cortex (N=103)

Model components	ß coefficient estimate	predictors	predictor beta-coefficient estimate	standard error	approximate degrees of freedom	*p*-value
$ß_{00}$ intercept	2.04×10^{-2}	*Empathic concern*	$-(2.49\times10^{-2})$	1.80×10^{-2}	7812	.17
		Empathic cheerfulness	3.41×10^{-3}	2.12×10^{-2}	7812	.87
		Empathic happiness	$-(7.51\times10^{-3})$	1.40×10^{-2}	7812	.59
		Low intensity pleasure	$-(3.07\times10^{-2})$	2.70×10^{-2}	7812	.26
$ß_{10}$ (linear component)	$-(4\times10^{-6})$	*Empathic concern*	$-(6.44\times10^{-4})$	8.31×10^{-4}	99	.44
		Empathic cheerfulness	$-(9.4\times10^{-5})$	9.10×10^{-4}	99	.92
		Empathic happiness	8.5×10^{-5}	5.5×10^{-4}	99	.87
		Low intensity pleasure	3.71×10^{-5}	9.2×10^{-4}	99	.69
$ß_{20}$ (Epoch 1 quadratic component)	$-(2\times10^{-6})$	*Empathic concern*	$-(2.1\times10^{-5})$	2.2×10^{-5}	99	.33
		Empathic cheerfulness	9×10^{-6}	2.1×10^{-5}	99	.68
		Empathic happiness	$-(3\times10^{-6})$	1.2×10^{-5}	99	.78
		Low intensity pleasure	2.2×10^{-5}	2.5×10^{-5}	99	.38
$ß_{30}$ (Epoch 2 quadratic component)	3×10^{-6}	*Empathic concern*	$-(9\times10^{-6})$	1.9×10^{-5}	99	.64
		Empathic cheerfulness	1×10^{-6}	2×10^{-5}	99	.97
		Empathic happiness	$-(5\times10^{-6})$	1.3×10^{-5}	99	.67
		Low intensity pleasure	$-(2.6\times10^{-5})$	2.1×10^{-5}	99	.21
$ß_{40}$ (Epoch 3 quadratic component)	3×10^{-6}	*Empathic concern*	$-(2.2\times10^{-5})$	3.3×10^{-5}	99	.51
		Empathic cheerfulness	$-(7.3\times10^{-5})$	2.7×10^{-5}	99	.009**
		Empathic happiness	6.7×10^{-5}	3.1×10^{-5}	99	.03*
		Low intensity pleasure	$-(4.5\times10^{-5})$	4.1×10^{-5}	99	.27

Note:

* $p < .05$.

** $p < .01$.

Table 6

Hierarchical EEG Asymmetry Model for Frontopolar Prefrontal Cortex (N=103)

Model components	ß coefficient estimate	predictors	predictor beta-coefficient estimate	standard error	approximate degrees of freedom	*p*-value
$ß_{00}$ intercept	3.2×10^{-2}	*Empathic concern*	$-(1.46\times10^{-2})$	1.82×10^{-2}	7557	.42
		Empathic cheerfulness	5.27×10^{-3}	2.15×10^{-2}	7557	.81
		Empathic happiness	2.06×10^{-2}	1.37×10^{-2}	7557	.13
		Low intensity pleasure	$-(4.18\times10^{-2})$	2.76×10^{-2}	7557	.13
$ß_{10}$ (linear component)	5.3×10^{-5}	*Empathic concern*	1.4×10^{-3}	8.16×10^{-4}	99	.09
		Empathic cheerfulness	9.5×10^{-4}	8.9×10^{-4}	99	.29
		Empathic happiness	$-(8.8\times10^{-4})$	6.8×10^{-4}	99	.20
		Low intensity pleasure	1.8×10^{-3}	8.9×10^{-4}	99	.047*
$ß_{20}$ (Epoch 1 quadratic component)	$-(9\times10^{-6})$	*Empathic concern*	$-(4.3\times10^{-5})$	1.7×10^{-5}	99	.02*
		Empathic cheerfulness	$-(5\times10^{-6})$	2.1×10^{-5}	99	.81
		Empathic happiness	1.2×10^{-5}	1.3×10^{-5}	99	.39
		Low intensity pleasure	$-(2.1\times10^{-5})$	2.2×10^{-5}	99	.35
$ß_{30}$ (Epoch 2 quadratic component)	2×10^{-6}	*Empathic concern*	$-(3.1\times10^{-5})$	1.7×10^{-5}	99	.07
		Empathic cheerfulness	$-(9\times10^{-6})$	1.7×10^{-5}	99	.57
		Empathic happiness	2.2×10^{-5}	1.4×10^{-5}	99	.11
		Low intensity pleasure	$-(2.9\times10^{-5})$	1.9×10^{-5}	99	.14
$ß_{40}$ (Epoch 3 quadratic component)	2.4×10^{-5}	*Empathic concern*	$-(3.6\times10^{-5})$	2.5×10^{-5}	99	.17
		Empathic cheerfulness	$-(5.8\times10^{-5})$	2.7×10^{-5}	99	.04*
		Empathic happiness	4.5×10^{-5}	2.7×10^{-5}	99	.09
		Low intensity pleasure	$-(1\times10^{-4})$	2.8×10^{-5}	99	.0001**

Note:

* *p* <.05.

** p <.01.

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Table 7

Empathic Emotions Relate to Specific Patterns of Prefrontal EEG Asymmetry during the Elicitation of Pleasure (N=103)

Empathy subtype exhibited during the empathy task	Dorsolateral EEG asymmetry during the pop-out toy task	Frontopolar EEG asymmetry during the pop-out toy task	Overall prefrontal pattern
empathic cheerfulness during the pain simulation period of the empathy task	Left	Slightly left→Strong left	Left prefrontal activity
empathic happiness during the relief period of the empathy task	Symmetrical→Slightly left	Symmetrical	Asymmetrical prefrontal activity (co-activation)
Empathic concern during the pain simulation period of the empathy task	Right→Left	Symmetrical→Right→Left	Intermittent left and right prefrontal activity