THE ROLE OF CROSS-BRAIN CONNECTIVITY IN EMOTION REGULATION WITHIN THE PARENT-ADOLESCENT DYAD

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Title of Study: THE ROLE OF CROSS-BRAIN CONNECTIVITY IN EMOTION REGULATION WITHIN THE PARENT-ADOLESCENT DYAD

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Abstract: Emotion regulation is influential in adolescent mental health outcomes. Specifically, poor emotion regulation skills and strategies have been shown to be related to increased rates of depression and anxiety. Parenting plays a large role in children's development of effective emotion regulation skills and strategies. Daily interactions between parents and adolescents influence the development of emotion regulation; however, little is known regarding the neural mechanisms that underlie these interactions. Using fMRI hyperscanning, the current study examined the role of cross-brain connectivity in emotion processing regions of parents' and adolescents' brains. Results indicate increased cross-brain connectivity in emotion processing regions is associated with more positive parent-adolescent interactions, greater adolescent-perceived supportive parenting, and fewer adolescent emotion regulation difficulties and depressive symptoms.

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CHAPTER I

INTRODUCTION

Adolescence is marked by high levels of emotionality and socialization as well as changes in perceptions of self and others (Albert & Steinberg, 2011). During this developmental period, novel affective experiences are ubiquitous as adolescents become more autonomous individuals, and the ability to regulate one's emotions is imperative in building and maintaining social relationships. Although adolescence is generally characterized by increases in independence, the parent-adolescent relationship remains influential in shaping adolescents' emotion regulation abilities (Guyer, Silk, & Nelson, 2016; Morris, Criss, Silk, and Houltberg, 2017).

Rates of depression are currently rising in the U.S. with nearly 13% of all adolescents reporting at least one major depressive episode and nearly 50% reporting any lifetime mental disorder (Merikangas et al., 2010). Research has found adolescents with greater difficulties regulating their emotions have an increased risk of developing depression and anxiety (Malik, Wells, & Wittkowski, 2015; Tortella-Feliu, Balle, & Sesé, 2010). Adolescents whose parents are more emotionally supportive show greater emotional competence and in turn have more positive mental health outcomes (Morris, Silk, Steinberg, Meyers & Robinson, 2007; Yap, Schwartz, Byrne, Simmons, & Allen, 2010). Moreover, parenting behaviors and techniques are associated with both structural and functional changes in brain regions associated with emotion processing and regulation (Romund et al., 2016; Whittle et al., 2014; Whittle et al., 2011). Because parenting plays such a large role in the development of adolescent emotion regulation and subsequent mental health, it is crucial to explore the neural mechanisms underlying this association within the context of the parent-adolescent relationship.

Emerging research on the role of cross-brain associations in social interactions may prove useful in better understanding the influence of parenting on adolescent emotion regulation. Neural synchrony, measured in brain-to-brain experiments, is the ability of a population of neurons in a particular region in one brain to fire at the same frequency as a population of neurons in the same region in another brain, specifically during a social interaction (Kinreich, Djalovski, Kraus, Louzoun, & Feldman, 2017). However, because emotion regulation develops through a process of parent self-regulation, co-regulation, and ultimately child self-regulation, it is likely parents and children recruit different regions of the brain to accomplish these goals. Referred to as cross-brain connectivity, we suggest this temporal synchronization in different regions of two individuals' brains is a form of neural synchrony. Due to the similarity of synchrony and cross-brain connectivity, it is plausible that, like neural synchrony, cross-brain connectivity may aid in dyadic communication and cooperation. As such, it is expected the literature on neural synchrony will serve to inform research on cross-brain connectivity.

The dorsolateral prefrontal cortex (dlPFC), insula, and amygdala have been found to be associated with emotion processing and regulation in adolescents, making them especially relevant regions for the current study (Aupperle et al., 2016; Baas, Aleman, & Kahn, 2004; Lee, Siegle, Dahl, Hooley, & Silk, 2014). Aupperle and colleagues (2016) found greater symptoms of depression and anxiety in a sample of adolescent females was related to increased right amygdala activation in response to maternal praise. Additionally, in a similar fMRI study examining adolescents' neural responses to parental criticism, youth showed increased activation in the dlPFC, posterior insula, and amygdala (Lee, Siegle, Dahl, Hooley, & Silk, 2014). In a study of parents and adolescents, researchers found resting state connectome similarity was related to greater parent-adolescent emotion synchrony on a daily basis as well as high levels of adolescent emotional competence (Lee, Miernicki, & Telzer, 2017).

Due to the novelty of this research and the difficulty in obtaining simultaneous measures of brain activity, no studies to our knowledge have examined cross-brain connectivity within the context of the parent-adolescent relationship, using real-time methods. Hyperscanning is the simultaneous scanning of two or more individuals which allows researchers to examine the influence of social interactions on brain function in real time. This technology allows for a more naturalistic social interaction between parent and adolescent. Therefore, through the use of hyperscanning, the current study seeks to first examine evidence of parent-adolescent cross-brain connectivity during a conflict discussion task as well as associations between cross-brain connectivity and the quality of the parent-adolescent interaction during the task. Additionally, the study seeks to investigate how parent-adolescent cross-brain connectivity in regions of the brain associated with emotion processing and regulation is related to adolescent emotion regulation, adolescent depressive symptoms, and adolescent-perceived supportive parenting.

CHAPTER II

REVIEW OF LITERATURE

Understanding parent-adolescent social interactions is essential when considering the development of adolescent emotion regulation and psychopathology. The parent-child relationship plays an influential role in children's social and emotional development including the ability to successfully recognize and regulate emotions in the self and others (Morris et al., 2007). Effective emotion regulation skills are essential for the development of healthy relationships and are related to positive behavioral and psychological outcomes, including lower rates of internalizing and externalizing symptoms (Eisenberg, Spinrad, & Eggum, 2010; Morris, Criss, Silk, and Houltberg, 2017). Typically, the quality of the parent-child relationship is measured on the behavioral level, often with specific focus on the dynamic exchange between parent and child. Through these observations at the behavioral level, researchers have discovered a sort of natural "flow" or exchange of information from the parent to the child and vice versa (Leclere, Viaux, Avril, Achard, Chetouani, Missonier, & Cohen, 2014). In parents and children who report lower relationship quality, such as lower parent responsiveness, this flow appears to be underdeveloped and less dynamic in nature (Harrist, & Waugh, 2002). However, dyads reporting a more positive parent-child relationship have been characterized by greater reciprocity or synchrony. In a series of studies measuring emotional, behavioral, and physiological parent-child synchrony, Feldman and colleagues have found that high levels of synchrony are associated with more positive developmental outcomes such as self-regulation, cognitive reappraisal, and greater empathy throughout childhood and adolescence (Feldman, Greenbaum, & Yirmiya, 1999; Feldman, 2007), suggesting parent-child synchrony may play a vital role in the development of emotion regulation.

The Importance of Parent-Child Synchrony

Simply stated, synchrony is “the coordination of behavior between interacting partners during social contact” (Apter-Levi, Zagoory-Sharon, & Feldman, 2013, p. 1). Sometimes referred to as rhythm or reciprocity, synchrony encompasses communication and emotions, both verbal and nonverbal, as well as the coordination, adaptability and familiarity between parents and children (Leclere et al., 2014). Additionally, synchrony is developed through emotional, behavioral, and even physiological and biological patterns between the parent and child (Leclere et al., 2014). On the behavioral and emotional level, synchrony includes gestures, postures, facial displays, and vocalizations (Feldman, 2007). Physiological and biological synchrony, often referred to as bio-behavioral synchrony, encompass genetic, hormonal, physiological, and neural processes underlying interactions in the parent-child relationship (Feldman, 2012). From the macro-level to the micro-level, there are many ways in which parent-child synchrony can manifest itself; however, regardless of how we measure synchrony, it is important to understand how synchrony influences child and adolescent social and emotional development.

Research findings suggest parent-child synchrony promotes healthier child attachment and bonding, greater parent-child relationship quality, and positive mental and behavioral health outcomes (Feldman, 2012). Ample research has investigated the role of synchrony in the parent-infant relationship. Feldman and Eidelman (2004) found that lower parent-infant synchrony, as measured behaviorally through observation, was associated with greater child behavior problems. Additionally, Feldman (2005) found lower verbal IQ and behavioral adaptation in infants whose mothers displayed less affective involvement during social interactions. These same infants also showed lower physiological regulation as measured by vagal tone throughout infancy. When followed up in adolescence, those identified as having had lower parent-infant behavioral synchrony showed a lower capacity for empathy (Feldman, 2005). These findings point to the potential role parent-child synchrony plays in the development of emotion regulation. Similar to Feldman, Blandon and colleagues (2008) found depressed mothers who were less able to provide reciprocal parenting had children who showed greater emotion dysregulation as reported by the children's mother and current teacher. In a study examining mother-child behavioral synchrony, researchers found highly synchronous dyads displayed greater levels of openness and lower levels of conflict, and children from highly synchronous dyads engaged in lower levels of anti-social behavior and had greater social skills (Criss, Shaw, & Ingoldsby, 2003), suggesting again that synchrony plays an influential role in the development of emotion regulation strategies and subsequent psychopathology in children.

Studies of parent-adolescent synchrony and emotion regulation have shown similar findings. In a study conducted by Barber, Bolitho, and Bertrand (2001), results indicated greater parent-adolescent behavioral and affective synchrony were related to less emotional adjustment issues including hyperactivity, conduct disorder, and somatization disorder. A study examining mother-adolescent relationship quality found youth who spent more time with their parents and received greater parental supervision had lower levels of salivary cortisol, a stress hormone. Furthermore, these same adolescents showed greater cortisol synchrony with their mother, which was associated with higher adolescent positive affect, providing further evidence for the bio-behavioral synchrony theory (Papp, Pendry, & Adam, 2009). However, in a similar study examining mother-daughter cortisol synchrony, researchers found mothers with a history of maternal depression and their never-depressed daughters showed higher cortisol production compared to healthy control mothers and their daughters (LeMoult, Chen, Foland-Ross, Burley, & Gotlib, 2015). Cortisol dysregulation has been found in adolescents at risk for depression (Goodyer, Herbert, Tamplin, & Altham, 2000), thus cortisol synchrony between depressed mothers and never-depressed daughters may serve as a biological risk factor in the development of adolescent depression. Taken together, these findings highlight the importance of behavioral and physiological synchrony in adolescent social and emotional development as well as provide a foundation for investigating neural synchrony in parents and children.

Understanding Neural Synchrony

Though often measured on the behavioral level, synchrony can also be measured on the molecular level in neurons through the use of electroencephalogram (EEG), dual functional near-infrared spectroscopy (fNIRS), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) technology. In order to investigate the role of brain-to-brain synchrony, we must first understand how synchrony occurs on the neuronal level. The most studied mechanism by which synchrony is thought to occur is through oscillations in the brain (Kinreich, Djalovski, Kraus, Louzoun, & Feldman, 2017). An oscillation occurs when a population of neurons fire simultaneously, go quiet, and then continue to repeat this process (Uhlhaas, Pipa, Lima, Melloni, Neuenschwander, Nikolic, & Singer, 2009). When dyads are synchronous, the oscillations in each of their brains take place at the same time, meaning whole populations of neurons are firing at the same time and then quieting continuously during a social interaction (Kinreich et al., 2017). It is important to note that "time" in the context of brain-to-brain synchrony is referring to the frequency at which the neurons fire in coordination. Gamma-band oscillations, typically between 30 and 90 Hz, have been implicated in the relationship between social interactions and emotion regulation (Symons, El-Deredy, Schwartze, & Kotz, 2016) as well as other relevant forms of social connectedness (Kinreich et al., 2017). During a social interaction, a synchronous dyad's oscillations will fire at the same frequency.

Because synchrony can be measured based on oscillations in the brain, it follows that the majority of brain-to-brain synchrony studies have been conducted using EEG. Typically, in these studies dyads are interacting with simultaneously recorded EEG. In one study using this method, Kinreich and colleagues (2017) found significantly greater neural synchrony among romantic couples when compared to strangers, suggesting that synchrony is related to a dyad's level of social connectedness. Brain-to-brain synchrony, specifically in the temporal-parietal regions, was highest during moments of social gaze and expressed positive affect in the romantic couples reporting higher connectedness (Kinreich et al., 2017). Interestingly, both social gaze and expressed positive affect are some of the earliest forms of social interactions between parent and child, reflecting levels of social connectedness, bonding, and emotional attachment.

Parent-Child Neural Synchrony

As described previously, behaviors indicative of social synchrony occur as early as infancy through the verbal and non-verbal interactions between parent and infant. Current research has shifted to further explore the biological mechanisms through which social synchrony is made possible. Reindl and colleagues (2018) found increased neural synchrony, measured using fNIRS hyperscanning technology, during a parent-child cooperative task was associated with increased activation in the dorsolateral prefrontal cortex (dlPFC) and the frontopolar cortex (FPC), regions typically associated with higher order behavior including the cognitive control of one's emotions. Interestingly, when completing the cooperative task with a stranger, activation in the child's FPC mediated the association between parent and child emotion regulation skills. Furthermore, greater neural synchrony in the parent-child dyad, measured using fNIRS, was related to greater emotion regulation abilities (Reindl, Gerloff, Scharke, & Konrad, 2018). In a similar study conducted by Lee, Miernicki, and Telzer (2017), results showed correlations between parent and adolescent resting-state network connectivity predicted greater emotional synchrony on a daily basis as measured using Ecological Momentary Assessment (EMA). Adolescents reporting greater parent-adolescent emotional synchrony also displayed higher levels of emotional competence, suggesting parent-adolescent social interactions lay the foundation for adolescents' future social and emotional competence (Lee, Miernicki, & Telzer, 2017).

In a related fMRI study of mothers and infants examining mothers' brain responses to vignettes describing situations of social synchrony with their own infant versus an unknown infant, mothers showed greater activation in the dorsal anterior cingulate cortex (dACC) in response to vignettes describing their own infant (Atzil, Hendler, & Feldman, 2013). In other words, mothers considering behavioral synchrony with their own infant showed greater activation in the dACC, a region shown to play a large role in the processing of emotion. These findings suggest that not only does synchrony occur within the parent-child dyad, but that the brain recognizes synchronous situations based on social context and responds appropriately. Similarly, in a study of mother-child neural synchrony using MEG, researchers found mothers showed greater activation in the superior temporal sulcus (STS) - a region typically associated with social cognition and mirroring - during social interactions with their own child compared to an unknown child. Furthermore, the greater reciprocity present in the parent-child interaction, the greater activation in the STS for both mother and child (Levy, Goldstein, & Feldman, 2017).

Cross-Brain Connectivity

Emotion regulation is thought to develop through the process of parents modeling their own emotion regulation strategies, co-regulation between parent and child through parental guidance and emotional support, and ultimately, as the child grows older, they develop their own emotion regulation skills and strategies (Morris et al., 2017). Because parents and adolescents have two very different roles in the above processes, it follows that each may recruit different brain regions to accomplish these goals. Furthermore, we may also expect to see differences in recruited brain regions due to developmental differences in structure and function of emotion processing brain regions of the brain in adults and adolescents (Yurgelun-Todd, 2007). We refer to this phenomenon as cross-brain connectivity. Cross-brain connectivity is a form of neural synchrony, but rather than temporal synchrony in the same regions of two individuals' brains, it is a measure of temporal synchrony in two different regions of two individuals' brains. It can be conceptualized as an action and reaction between two brains during a social interaction. Most fMRI hyperscanning studies examine connectivity between the same regions in two individuals' brains (synchrony), however, to the best of my knowledge, only one other study has examined connectivity between different brain regions. Bilek and colleagues (2015) found evidence of cross-brain connectivity between interacting dyads during a hyperscanning fMRI joint attention task in which one member of the dyad (sender) indicates the location of a target on the screen with their gaze and the other member (receiver) must respond with the correct location. Cross-brain connectivity was found between the sender's right temporoparietal junction and the receiver's medial prefrontal cortex (mPFC) and orbitofrontal cortex. The researchers then related cross-brain connectivity to a behavioral measure of social connectedness. Interestingly, cross-brain connectivity was significantly higher for dyads with a larger social network, suggesting cross-brain connectivity may be a mechanism underlying social interactions.

The Current Study

Longitudinal research has established that behavioral patterns of parent-child synchrony remain stable from infancy to adolescence and play a large role in the development of emotion regulation (Feldman, 2010). Adolescence is characterized by high levels of emotionality and socialization, making it an important transitional period for the development of effective emotion regulation. Furthermore, first onset of mental illness typically occurs in early adolescence with treatments often occurring much later (Kessler, Amminger, Aguilar-Gaxiola, Alsonso, Lee, & Uston, 2007). Because of the influential role of parent-child behavioral synchrony in the development of emotion regulation, which is in turn associated with both internalizing and externalizing symptoms, further research is warranted to better understand the neural mechanisms that underlie parent-adolescent social interactions.

No studies have examined the role of cross-brain connectivity in the parent-adolescent dyad. A major constraint in the field is the inability to measure neural synchrony in both members of the dyad simultaneously, due to the need for multiple, linked MRI scanners. Through the use of concurrent fMRI scanning, or hyperscanning, the current study was able to explore cross-brain connectivity in real-time during a naturalistic parent-adolescent social interaction. Dyads completed an emotionally charged free-speech task in which parents and adolescents discuss conflicts that they choose. Regions of interest in this study included the dorsolateral prefrontal cortex (dlPFC), insula, and amygdala, as these regions have been associated with emotion processing and regulation in prior studies of adults and adolescents (Aupperle et al., 2016; Baas, Aleman, & Kahn, 2004 Lee, Siegle, Dahl, Hooley, & Silk, 2014). Using this technology, this study sought to explore the following questions: 1) is there evidence of parent-adolescent cross-brain connectivity during a conflict discussion task? 1) does the quality of social interactions relate to cross-brain connectivity in emotion processing regions of the parent and adolescent brain? 2) is parent-adolescent cross-brain connectivity in emotion processing regions in the adolescent and parent brain related to adolescent self-reported emotion regulation and depressive symptoms? 3) does adolescent perceived parenting behavior relate to cross-brain connectivity in emotion processing regions of the adolescent and parent brain?

Hypotheses

1. Evidence of parent-adolescent cross-brain connectivity will be found during the conflict discussion task.

2. More positive parent-adolescent discussions during the conflict task will be associated with greater parent-adolescent cross-brain connectivity in emotion processing regions (i.e., dlPFC, amygdala, insula).

3. Greater parent-adolescent cross-brain connectivity in emotion processing regions in the adolescent and parent brain (i.e., dlPFC, amygdala, insula) will be related to fewer adolescent self-reported emotion regulation difficulties and depressive symptoms.

4. Perceived parental support will be related to greater cross-brain connectivity in emotion processing regions in the parent and adolescent brain (i.e., dlPFC, amygdala, insula).

CHAPTER III

METHODOLOGY

Participants

Data were collected from 33 parent-adolescent dyads (N = 66) through public middle and high schools in an urban southern mid-west area. Adolescents in the sample were between 14 and 16 years of age (M = 14.6, 14% African American, 9% Latino American, 73% European American, <1% American Indian, 4% More than one race, 62% female). Parents included in the study were the biological parent, co-residing at least 4 days per week with the focal adolescent. Biological parents in the sample were 95% female with a mean age of 43 years. All parents and adolescents were psychiatrically healthy as determined using the Mini-International Neuropsychiatric Interview (MINI 7.0) structured diagnostic interview (Sheehan, et al., 1997). Additionally, all parents and adolescents met fMRI safety screening criteria as assessed using the MRI screening questionnaire developed by the Institute for Magnetic Resonance Safety, Education, and Research (IMRSER). All participants included in the study were right-handed and fluent in English. Exclusion criteria for the parent included a current psychiatric diagnosis or taking medications influencing fMRI. Exclusion criteria for adolescents included current or past psychiatric diagnosis, medications influencing fMRI, and/or neurodevelopmental delay. Additionally, both parents and adolescents were excluded if under the influence of alcohol or psychoactive drug on the day of their fMRI scan.

Participants were recruited through public high schools. Schools with higher percentages of free/reduced lunch were targeted, as past research has found adolescents from disadvantaged backgrounds show higher rates of anxiety and depression (Ingoldsby & Shaw, 2002). Dyads were recruited using fliers sent through Peachjar, a digital platform used by the school districts in the Tulsa Metropolitan area. The fliers included exclusion/inclusion criteria as well as a phone number to call if interested in the study. The study was approved by the university's Institutional Review Board.

Procedure

The study protocol consisted of an initial phone screen, a 2-hour lab visit, and a 3-hour scanning visit. Individuals interested in the study were directed to call the study research assistant located at the study site. Upon initial contact, the parent completed a brief phone screen to determine eligibility for the first visit. The phone screen included a standard fMRI safety screen survey as well as a mental and physical health screener to determine eligibility of both the adolescent and parent. Based on the phone screen, if the dyad was eligible, the parent and adolescent were asked to attend a 2-hour lab visit that included completion of surveys and a psychiatric interview.

During the initial 2-hour lab visit, dyads completed a battery of surveys assessing parent-child relationship, emotion awareness, mental and physical health, and other demographic information. Additionally, all participants completed a structured diagnostic interview. The Mini International Neuropsychiatric Interview, parent-MINI 7.0, and adolescent MINI KID 7.0 was used to determine current and past psychiatric diagnoses (Sheehan et al., 1997). Parents completed the fMRI safety screening assessment for their adolescent and for themselves.

Participants eligible for the fMRI visit completed the 3-hour scanning visit within 3 weeks of their initial visit. During the scanning visit, participants completed surveys assessing parent-child conflict, positive/negative affect, and the fMRI safety screening assessment for the second time. All participants completed a breathalyzer and saliva test to screen for alcohol and drug use prior to the scan. Both parent and adolescent females were required to take a pregnancy test prior to the scan, as the risks of fMRI on fetal development have not been fully explored. Height and weight were also collected.

Once in the scanner, participants had a structural scan. Each dyad completed the conflict discussion task while in the scanner (see Measures). fMRI hyperscanning technology was used to collect brain imaging data. Two identical GE MR750 3.0T scanner with NOVA 8 channel head coils were used to obtain all imaging data. Following the completion of the study, parents and adolescents were compensated for their time as well as given a shirt and CD with images of their brain.

Measures

Surveys:

The following surveys were completed by each adolescent and used to assess adolescent-perceived supportive parenting and adolescent emotion regulation and symptoms of depression.

Parenting Behaviors and Techniques

The Alabama Parenting Questionnaire (APQ) was used to assess parenting behaviors and techniques (Frick, 1991). Adolescents completed the 42-item questionnaire which includes items assessing responsiveness, involvement, monitoring, corporal punishment, and hostility. For the current study, the involvement subscale was used to assess supportive parenting (α = .81). Example questions include, “You have a friendly talk with your child,” and “Your mom/dad asks about your day in school.” Questions are completed on a 5-point Likert scale from 1 = “never” to 5 = “always”. The scores were summed to compute the supportive parenting variable.

Adolescent Emotion Regulation

To assess adolescent emotion regulation, the 36-item Difficulties in Emotion Regulation Scale (DERS) was completed by adolescents (Gratz & Roemer, 2004). The DERS consists of 6 subscales: lack of emotional awareness, lack of emotional clarity, difficulties controlling impulsive behavior, difficulties engaging in goal-directed behavior, nonacceptance of negative emotional responses, and limited access to emotion regulation strategies. In addition, an overall score can be obtained, with higher scores indicating greater emotion regulation difficulties. For the current study, the lack of emotion clarity subscale was used (α = .74) as well as the overall score (α = .83). Examples items include, “I am confused about how I feel,” and “When I am upset, I become out of control.” Questions are completed on a 5-point Likert scale from 0 = “almost never” to 5 = “almost always”. The scores on the overall scale and lack of emotional clarity subscale were summed to compute the DERS variable and the DERS-Clarity variable, respectively.

Adolescent Symptoms of Depression

Adolescents completed the 33-item Mood and Feelings Questionnaire which assesses symptoms of depression (MFQ; Angold & Costello, 1987). MFQ example questions include, “I didn’t enjoy anything at all,” and “I felt grumpy and cross with my parents.” Questions are completed on a 3-point Likert scale from 0 = “not true” to 2 = “true” (α = .8). The scores were summed to compute the adolescent depression variable.

fMRI Conflict Discussion Task:

Prior to scanning, each member of the dyad completed the Conflict Frequency Questionnaire (Melby et al., 1998) to determine which conflicts are most common between the parent and focal adolescent. The 33-item questionnaire consists of 32 possible conflict topics as well as an “other” category to list any topics not covered in the questionnaire. Some of the topics included, “Activities with friends,” “Attitude/respect,” “Chores at home,” “Homework,” and “Use of computer/phone.” Parents and adolescents were asked to rate how often in the past year they had each disagreement with their parent/adolescent on a 5-point Likert scale from “Never” to “Very Often.” Following these ratings, parents and adolescents were asked to rate their top 5 disagreements. The highest rated topics were selected for use in the conflict discussion task described below.

Each member of the dyad was fitted with a pair of headphones and microphone before being placed in the scanner. This allowed each member to listen and respond to one another, as if on the telephone, while being scanned. From the Conflict Frequency Questionnaire, 3 conflicts were programmed into the task (see Figure 1). Each member of the dyad was told that they would be discussing each of the 3 topics for 4 minutes for a total of 12 minutes. During the first 2 minutes, the dyad was asked to describe the conflict presented on the screen. This is referred to as the “describe” condition and was intended to illicit negative emotion. The second 2 minutes the dyads were asked to come up with a solution for the conflict. This is referred to as the “solution” condition and was intended to engage the parent and adolescent in problem solving. A timer was presented on the screen, so dyads could keep track of how much time they had left.

Conflict Discussion Quality

The audio recorded during the conflict discussion task was recorded, transcribed, and coded for positive and negative statements based on the coding manual used by Eisenberg and colleagues (2008) adapted from three scoring manuals of parent-child interactions: Autonomy and Relatedness Coding System (Allen, Hauser, Bell, Boykin & Tate, 1994); Family and Peer Process Code (Stubbs, Crosby, Forgatch, & Capaldi, 1998); and Kahen Affect Coding System; Gottman, Katz, & Hooven, 1996, 2013). All transcriptions were coded by two lab personnel trained in qualitative data coding. Reliability coding was completed for 26% of the transcriptions with 80% reliability found between the coders.

For the purposes of this study, behavioral codes such as those used for facial expressions were removed. Eleven possible coding categories were used (5 positive and 6 negative). Positive categories included validation, agree, humor, elicit opinion, and offer solution. Negative categories included disagree, put down, derisive humor, coerce, interrupt, and stonewall (see Table 1 for example coded statements). Statements that did not fall into one of these 11 categories were considered non-coded statements.

For the current study, the variable parent positivity was measured by the ratio of parent positive statements to overall coded statements during the conflict discussion task. Similarly, the variable adolescent positivity was measured by the ratio of adolescent positive statements to overall coded statements, and the variable overall positivity was measured by the ratio of parent and adolescent positive statements to overall coded statements during the conflict discussion task.

Cross-brain Connectivity

Cross-brain connectivity is a measure of temporal synchrony in two different regions of two individuals' brains. In the current study, cross-brain connectivity was operationalized by calculating the signal time course correlation between a seed region in one individual's brain and each voxel in the other individual's brain. Due to variability in brain response, it was necessary to use a lagged cross-correlation analysis (see *Statistical Analysis* section). Bilek et al. (2015) used a similar approach to calculate cross-brain connectivity two seed regions in two individual's brains using independent component analysis (ICA).

MRI and fMRI Data Acquisition

Two General Electric Discovery MR750 whole-body 3 Tesla MRI scanners, identical in hardware and software configuration, were used to acquire the functional and structural brain images. Both scanners are capable of conducting advanced parallel fMRI, or hyperscanning. Eight-element surface coil head coils were used for MRI signal reception. Blood-oxygenation level-dependent (BOLD) fMRI scans were obtained with a single-shot gradient-recalled EPI sequence with sensitivity encoding (SENSE). The following EPI parameters were used: FOV/slice/gap = 240/2.9/0 mm, 41 axial slices per volume, acquisition matrix = 96 x 96, repetition/echo time (TR/TE) = 2000/25 ms, SENSE acceleration factor $R = 2$ in the phase encoding (anterior-posterior) direction, flip angle = 78°, sampling bandwidth = 250 kHz, number of volumes = 148, scan time = 4 min and 56 s. EPI images were reconstructed into a 128 x 128 matrix, with an fMRI voxel volume of 1.875 x 1.875 x 2.9 mm^3.

Each participant's EPI images were aligned to a T1-weighted MRI scan with magnetization-prepared rapid gradient echo (MPRAGE) sequence with SENSE for structural and anatomical reference. The following parameters were used for MPRAGE sequence: FOV/slice = 240/0.9 mm, 180 axial slices per volume, image matrix = 256 x 256, voxel volume = 0.94 x 0.94 x 0.9 mm^3, TR/TE = 5/2.012 ms, SENSE acceleration factor $R = 2$, flip angle = 8°, inversion/delay time (TI/TD) = 725/1400 ms, sampling bandwidth = 31.25 kHz, scan time = 6 min and 13 s.

fMRI Data Preprocessing

All imaging analyses were performed using AFNI. Each participant's anatomical scan was aligned to the first volume of the EPI data, and anatomical scans were spatially transformed to Montreal Neurological Institute (MNI) space. In order for the signal to reach a steady state, the first four fMRI volumes were excluded from analysis. The EPI data were resampled to a 2 x 2 x 2 mm grid and spatially smoothed with a 6 mm full-width at half-maximum Gaussian kernel.

Due to the difficulty in obtaining valid fMRI data during a free speech paradigm, we employed a speech-related de-noising procedure developed by Xu and colleagues (2014). This de-noising procedure suppresses motion-related artifacts in fMRI data by employing a dual-mask spatial independent component analysis (ICA) method which identifies speech motion-related artifacts based on their extracerebral origins. Noise components were removed using an automated independent component classifier and subtracted from the time series. Standard motion-censoring algorithms were used following the de-noising procedure to protect against any remaining speech-related artifacts.

Statistical Analysis

For each dyad, maximum cross-correlations between the signal time course of the parents' emotion processing and regulation brain regions, referred to as seed regions (e.g., dlPFC, amygdala, and anterior insula), with the adolescents' time course of the BOLD signal in the whole brain during the conflict discussion were calculated. Cross-correlations between the signal time course of the adolescent seed regions (e.g., dorsolateral prefrontal cortex, amygdala, and anterior insula) with the parents' BOLD signal time course were also calculated. This was done separately for the describe and solution conditions. The cross-correlations were then averaged separately across the three runs for the describe block and the solution block. Whole brain analysis was done for two reasons: 1) the analysis method detailed above is based on seed-based functional connectivity analysis which measures connectivity in one individual's brain by calculating the correlation between the signal time course of the seed region with all other voxels in the brain; 2) whole brain analysis can provide useful information regarding brain regions that may not have been selected *a priori* due to the novelty of the current study.

The seed regions were selected *a priori*. The amygdala seed regions were defined anatomically using masks created by FreeSurfer. Six millimeter spheres centered around these MNI coordinates identified in meta-analyses were used to create the following seed regions: anterior insula – (+/-40, 11, 2; Xu, Xu, & Yang, 2016), and dlPFC (+/-44, 34, 28; identified using the search term "dlPFC" on Neurosynth [Yarkoni et al., 2011]).

The BOLD signal change associated with external stimuli such as “stop” conversation cues as well as nuisance covariates of motion parameters and slow signal fluctuations were regressed out. The signal time series during each block of discussion (“describe” and “solution”) was extracted from the residual signal. The initial four fMRI volumes in each block were removed to compensate hemodynamic response delay. Cross-correlations between the parent and adolescent signals were then calculated for each block. Because of variability in individual brain response, maximum absolute cross-correlation in -6s to -2s lag (negative lag), 0-lag (simultaneous - no lag), and in +2s to +6s lag (positive lag) were evaluated separately. For the cross-correlations between the adolescent seed region and the parent whole brain, negative lag indicates the effect from the adolescent brain to the parent brain; whereas, positive lag indicates the effect from the parent brain to the adolescent brain. For the cross-correlations between the parent seed region and the adolescent whole brain, negative lag indicates the effect from the parent brain to the adolescent; whereas, positive lag indicates the effect from the adolescent brain to the parent brain. The results were conservatively corrected for multiple comparisons using false discovery rate (FDR) thresholded with voxel-wise $p < 0.001$ with cluster-size-corrected $p < 0.05$. For group analysis, unbiased normalization was applied to the cross-correlation coefficients.

The resulting normalized cross-correlation coefficients reflected the degree of parent-adolescent cross-brain connectivity. These values were then used in correlation analysis with measures of parent-adolescent social interaction quality (conflict discussion task), measures of adolescent depression (MFQ) and emotion regulation difficulties

(DERS), and parenting measures (APQ) to determine how the parent-adolescent relationship is related to cross-brain connectivity.

CHAPTER IV

FINDINGS

Results

Correlations between all survey measures can be found in Table 2. The cross-correlation analyses, used to test the first hypothesis, identified several significant clusters providing evidence for the existence of cross-brain connectivity between parent and adolescent. The following two sections describe these associations. The first section presents the results of the cross-correlations between the selected seed regions in the adolescent brain (dlPFC, amygdala, and anterior insula) and the parent whole brain (see Table 3), with negative lag indicating the effect from the adolescent brain to the parent brain and positive lag indicating the effect from the parent brain to the adolescent brain. The second section presents the results of the cross-correlation between the selected seed regions in the parent brain (dlPFC, amygdala, and anterior insula) and the adolescent whole brain (see Table 4), with the negative lag indicating the effect from the parent brain to the adolescent and positive lag indicating the effect from the adolescent brain to the parent brain.

Child Region of Interest/Parent Whole Brain

For the describe block, significant positive lag (parent predicting adolescent) cross-correlations were found between activation in the adolescent right anterior insula and the parent bilateral medial frontal gyrus, and the adolescent right anterior insula and the parent right middle frontal gyrus. The medial and middle frontal gyri are typically associated with memory and attention control (Petrides & Pandya, 2012).

For the solution block, a significant negative lag (adolescent predicting parent) cross-correlation was found between activation in the adolescent left amygdala and the parent left precuneus. The left precuneus has been shown to be associated with memory retrieval, self-related processing, and perception of pain (Cavanna, & Trimble, 2006). A significant positive lag cross correlation was found between activation in the adolescent left amygdala and the parent right thalamus, which plays a crucial role in emotion processing and empathy (Nummenmaa, Hirvonen, Parkkola, & Hietanen, 2008). A significant positive lag cross correlation was found between activation in the adolescent left anterior insula and the parent left postcentral gyrus. The postcentral gyrus is found in the primary motor cortex and has been found to play a role in emotion recognition (Heberlein & Saxe, 2005). A significant positive lag cross correlation was found between activation in the adolescent right anterior insula and the parent right middle occipital gyrus, an area typically activated during perceptual and cognitive tasks (Renier, Anurova, De Volder, Carlson, VanMeter, & Rauschecker, 2010).

Parent Region of Interest/Child Whole Brain

For the describe block, a significant positive lag (adolescent predicting parent) cross-correlation was found between activation in the parent left amygdala and the adolescent left precentral gyrus, which plays a similar role as the postcentral gryus in emotion recognition in others (Heberlein & Saxe, 2005). A significant positive lag cross-correlation was found between activation in the parent left amygdala and the adolescent left posterior cingulate, an area associated with emotion processing and regulation

(Aupperle et al., 2016; Baas, Aleman, & Kahn, 2004; Lee, Siegle, Dahl, Hooley, & Silk, 2014). Significant positive lag cross-correlations were found between activation in the parent right anterior insula and the adolescent right inferior and middle occipital gyrus. Significant positive lag cross-correlations were found between activation in the parent left and right anterior insula and the adolescent right middle temporal gyrus. The right middle temporal gyrus has been associated with executive functioning, including the retrieval of semantic information (Davey et al., 2016).

Significant negative lag (parent predicting child) cross-correlations were found between activation in the parent left dlPFC and adolescent right and left dorsal anterior cingulate cortex (dACC). The anterior cingulate cortex is a region in the limbic system associated with cognitive and emotion processing (Bush, Luu, & Posner, 2000). A significant negative lag cross-correlation was found between activation in the parent left anterior insula and the adolescent right superior frontal gyrus, which is associated with higher cognitive functions such as memory retrieval (Boisgueheneuc et al., 2006).

For the solution block, significant positive lag cross-correlations were found between activation in the parent left anterior insula and the adolescent bilateral precuneus and bilateral posterior cingulate. A significant positive lag cross-correlation was found between activation in the parent right dlPFC and adolescent right postcentral gyrus.

Cross-Brain Connectivity and Parent-Adolescent Interaction

To test the second hypothesis, the averaged cross-correlation coefficients were correlated with parent positivity, adolescent positivity, and overall positivity. During the describe block, cross-brain connectivity for the parent left dlPFC seed region predicting the adolescent right superior frontal gyrus was significantly and positively correlated with adolescent positivity (r = 0.35, $p < 0.05$; see Figure 2). During the solution block, cross-brain connectivity for the adolescent right precuneus predicting the parent left anterior insula seed region was significantly and positively associated with parent positivity (r = 0.38, $p < 0.05$), adolescent positivity (r = 0.45, $p < 0.05$), and overall parent and adolescent positivity (r = 0.62, $p < 0.001$; see Figure 3).

Cross-Brain Connectivity and Adolescent ER and Depression

To test the third hypothesis, the average cross-correlation coefficients were correlated with adolescent-reported emotion regulation difficulties and depressive symptoms. During the describe block, cross-brain connectivity for the parent right middle frontal gyrus predicting the adolescent right anterior insula seed was significantly and negatively correlated with adolescent-reported DERS (r = -0.38, $p < 0.05$) and the emotional clarity subscale of the DERS (r = -0.45, $p < .05$; see Figure 4). Cross-brain connectivity for the parent right medial frontal gyrus predicting the adolescent right anterior insula seed was significantly and negatively correlated with adolescent depressive symptoms (r = -0.37, $p < 0.05$; see Figure 5).

Cross-Brain Connectivity and Positive Parenting

To test the fourth hypothesis, the average cross-correlation coefficients were correlated with adolescent-reported supportive parenting. During the solution block, cross-brain connectivity for the parent left postcentral gyrus predicting the adolescent left anterior insula seed was significantly and positively correlated with adolescent-reported supportive parenting (r = 0.50, $p < 0.05$; see Figure 6) indicating decreased cross-brain connectivity in these regions of the parent and adolescent brain was associated with greater adolescent perceived parental involvement.

CHAPTER V

CONCLUSION

Discussion

The current study provides evidence for the existence of parent-adolescent cross-brain connectivity using fMRI hyperscanning and explores associations between this phenomenon and parenting, adolescent emotion regulation, and adolescent depressive symptoms. In regard to the first hypothesis, several significant clusters were found representing parent-adolescent cross-brain connectivity. Regions activated in the parent brain, including the precuneus, thalamus, and postcentral gyrus, play important roles in empathy and the recognition of other's emotions (Cavanna, & Trimble, 2006; Heberlein & Saxe, 2005; Nummenmaa et al., 2008), lending support to the idea of parents' role as emotion co-regulators. Activation in the occipital gyrus was found in both parents and adolescents. Activation in the occipital gyrus is associated with emotion-provoking visual stimuli; however, because parents and adolescents were not able to see one another, it is difficult to determine why activation was correlated with emotion regulation seed regions. Interestingly, adolescent activation was typically found in emotion processing regions of the brain often associated with the self, including the posterior cingulate and dACC, suggesting adolescents were more focused on regulating their own emotions compared to thinking about their parent. Additionally, several regions associated with higher order executive functions (i.e., middle temporal gyrus and right superior frontal gyrus), such as decision making and memory retrieval, were activated in adolescents when parents' emotion processing seed regions were active. Taken together, these findings may provide additional support for the role of the parent as a co-regulator, providing the adolescent with emotional guidance, as the adolescent attempts to self-regulate. The presence of temporal synchrony in two *different* regions of the parent's and adolescent's brain may be due in part to these differential roles during the conflict discussion task.

In regard to the second hypothesis, greater cross-brain connectivity between the parents' left dlPFC and adolescents' right superior frontal gyrus was associated with more adolescent positive statements during the describe portion of the conflict discussion task. As discussed previously, the dlPFC is a region shown to be associated with emotion regulation strategies (Goldin, McRae, Ramel, & Gross, 2008). Past research indicates recruitment of the dlPFC during a conflict task can increase conflict resolution through the use of cognitive control strategies such as cognitive reappraisal and suppression (Egner, & Hirsch, 2005). This may suggest that parents who show greater activation in this region may be employing more effective emotion regulation strategies compared to parents with less activation in this region. The superior frontal gyrus is associated with attention control and memory and is thought to play an important role in cognitive development throughout adolescence (Boisgueheneuc et al., 2006; Klingberg, Forssberg, & Westerberg, 2002). Together with our findings, this may suggest that adolescents are able to maintain positivity during the conflict discussion task if both parent and adolescent are actively regulating their emotions.

Furthermore, the results indicated greater cross-brain connectivity between the adolescents' right precuneus and parents' left anterior insula was associated with fewer parent, adolescent, and overall negative statements during the conflict discussion task. Increased activation in the precuneus has been shown to be associated with greater self-related emotion processing in adults and adolescents. Moreover, past research indicates increased symptoms of depression among adolescents is associated with decreased activation in the precuneus and difficulty processing affective information (Ho et al., 2014). Greater activation in adolescents' precuneus may suggest an increased ability to process emotions, specifically in relation to the self. The anterior insula is thought to play a role in the processing and regulation of emotions in the self as well as emotion awareness in others (Lamm & Singer, 2010). Furthermore, neuroimaging studies have found individuals recruit the anterior insula when witnessing another's emotional or physical pain, when practicing a compassion-related task, or when shown pictures of their parents or children (Immordino-Yang, McColl, Damasio, & Damasio, 2009; Lamm, Batson, & Decety, 2007; Leibenluft, Gobbini, Harrison, & Haxby, 2004). Because the anterior insula is recruited when processing emotions based on the self and others, it has been suggested the region may play a role in the "shared network" account of empathy (Lamm & Singer, 2010). The shared network account is grounded in Simulation Theory which posits that we learn about others' emotions by referencing our own emotional experiences and are then able to simulate how the other person might feel and behave (Gallese, 2003).With this in mind, our findings might suggest that adolescent's emotion processing predicts parent emotion regulation which is correlated with positivity during conflict. Overall, the results suggest increased cross-brain connectivity between parent and adolescent may play a beneficial role during emotionally-charged social interactions.

In regard to the third hypothesis, greater cross-brain connectivity between the parent right middle frontal gyrus and the adolescent right anterior insula was associated with fewer adolescent emotion regulation difficulties. Similarly, greater cross-brain connectivity between the parent right medial frontal gyrus and the adolescent right anterior insula was associated with fewer adolescent depressive symptoms. Both the middle and medial frontal gyrus have been implicated in studies of attention-orienting. A study by Yamasaki and colleagues (Yamasaki, LaBar, and McCarthy, 2002) found increased activation in the middle frontal gyrus was associated with attentional stimuli but not emotional stimuli. Additionally, those less susceptible to emotional arousal were able to maintain attentional focus during higher cognitive processes (Yamaskai, LaBar, and McCarthy, 2002). Concerning adolescent anterior insula activation, Perlman and colleagues (Perlman et al., 2012) found adolescent healthy controls showed increased anterior insula activation during an emotion regulation task compared to adolescents diagnosed with major depressive disorder, suggesting this region may play a role in the successful regulation of emotions. This could suggest that parents who are better able to maintain attention and react less to emotionally-charged stimuli positively influence their adolescent's ability to regulate their own emotions, through recruitment of the anterior insula, resulting in fewer adolescent emotion regulation difficulties as well as fewer depressive symptoms.

In regard to the fourth hypothesis, less cross-brain connectivity between the parent left postcentral gyrus and adolescent left anterior insula was associated with greater adolescent-perceived parental support. In contrast with the above findings where we see increased activation in both regions of the parent and adolescent brain, here parents show increased activation in the left postcentral gyrus while adolescents show decreased activation in the anterior insula. Upon first glance, this may not appear to support the hypothesis, however, when examining Figure 6 further, we see that as cross-brain connectivity between these regions increases so does adolescent-perceived supportive parenting. Although limited, research suggests the postcentral gyrus may be related to recognition of others' emotions. A fMRI lesion study by Heberlein and Saxe (2005) found damage to the postcentral gyrus was associated with an impaired ability to recognize other's emotional states, suggesting it may play a role in emotion recognition and perspective-taking. These findings could suggest that more supportive parenting may be associated with greater cross-brain connectivity, as parents and children are both actively regulating their emotions; whereas, less supportive parenting may be associated with less cross-brain connectivity, as the parent is attempting to regulate for the adolescent rather than the adolescent attempting to self-regulate. However, additional research is warranted to further understand this association.

These findings provide novel support for the importance of cross-brain connectivity in parent-adolescent social interactions. Similar to other forms of parent-child synchrony, it appears greater cross-brain connectivity may aid in adolescent social and emotional development, as parents serve as co-regulators facilitating their adolescent's self-regulating abilities through daily social interactions. These reciprocal interactions between parent and adolescent may serve to enhance not only regulatory abilities but also social skills and competencies, as children learn to identify and predict emotions and behaviors in others. In addition, these results highlight the importance of supportive and empathetic parenting practices for positive developmental outcomes.

Past research indicates an element of social connectedness underlies neural synchrony and cross-brain connectivity (Bilek et al., 2015; Kinreich et al., 2017). In studies of both humans and animals, bio-behavioral synchrony is formed within the parent-infant relationship suggesting it plays a fundamental, and possibly adaptive, role in attachment and bonding (Kinreich et al., 2017; Rilling & Young, 2014). These first social relationships formed between parent and infant influence the development of the social brain providing the foundation for all future interactions. This relationship orients children to the social world, providing beliefs and expectations regarding social interactions. Beginning with the parent-child relationship, neural synchrony may be a mechanism underlying our sense of social connectedness and attachment with others. It is within this social context, that children learn to regulate their emotions as well as recognize and react to the emotions of others. Thus, both behavioral and neural synchrony in the parent-adolescent relationship may work in tandem to influence adolescent social and emotional development.

Limitations

The current study had a number of limitations. First, we were unable to examine sex differences due to power. In future analyses, we will need to identify sex as a control variable or variable of interest. Second, we observed a ceiling effect in the ratio of positive to overall coded statements from the conflict discussion task, specifically for adolescents, some of whom only made positive statements. Third, the cross-sectional study design limits our interpretation of the results. Without longitudinal data it is impossible to determine directionality of the relationships described above. Fourth, due to strict exclusion/inclusion criteria, our sample size was comparatively small. Finally, only two fathers were included in the current study, which limits our understanding of the neural circuitry underlying parent-adolescent interactions.

Strengths

The current study had several strengths including the use of an ecologically-valid fMRI hyperscanning task. By utilizing a naturalistic free-speech paradigm, we were able to better examine emotion-related neurocircuitry underlying parent-adolescent social interactions in real-time. Using this technology, we were able to examine cross-brain connectivity within the context of the parent-adolescent dyad. This study has provided novel evidence for the existence of cross-brain connectivity between parents and adolescents during a social interaction.

Implications

Due to the exploratory and novel nature of the current study, additional research is warranted to further understand the neurocircuitry underlying parent-adolescent interactions and their influence on adolescent development. Additional studies may ultimately inform prevention and intervention programs aimed at improving the parent-adolescent relationship as well as adolescent developmental outcomes. Neurofeedback studies have already proved useful in helping individuals manage their physiological and emotional responses to stimuli (Young, Zotev, Phillips, Misaki, Yuan, Drevets, & Bodurka, 2014). A neurofeedback intervention intended to educate parents and adolescents may prove useful in improving the parent-adolescent relationship and subsequent developmental outcomes.

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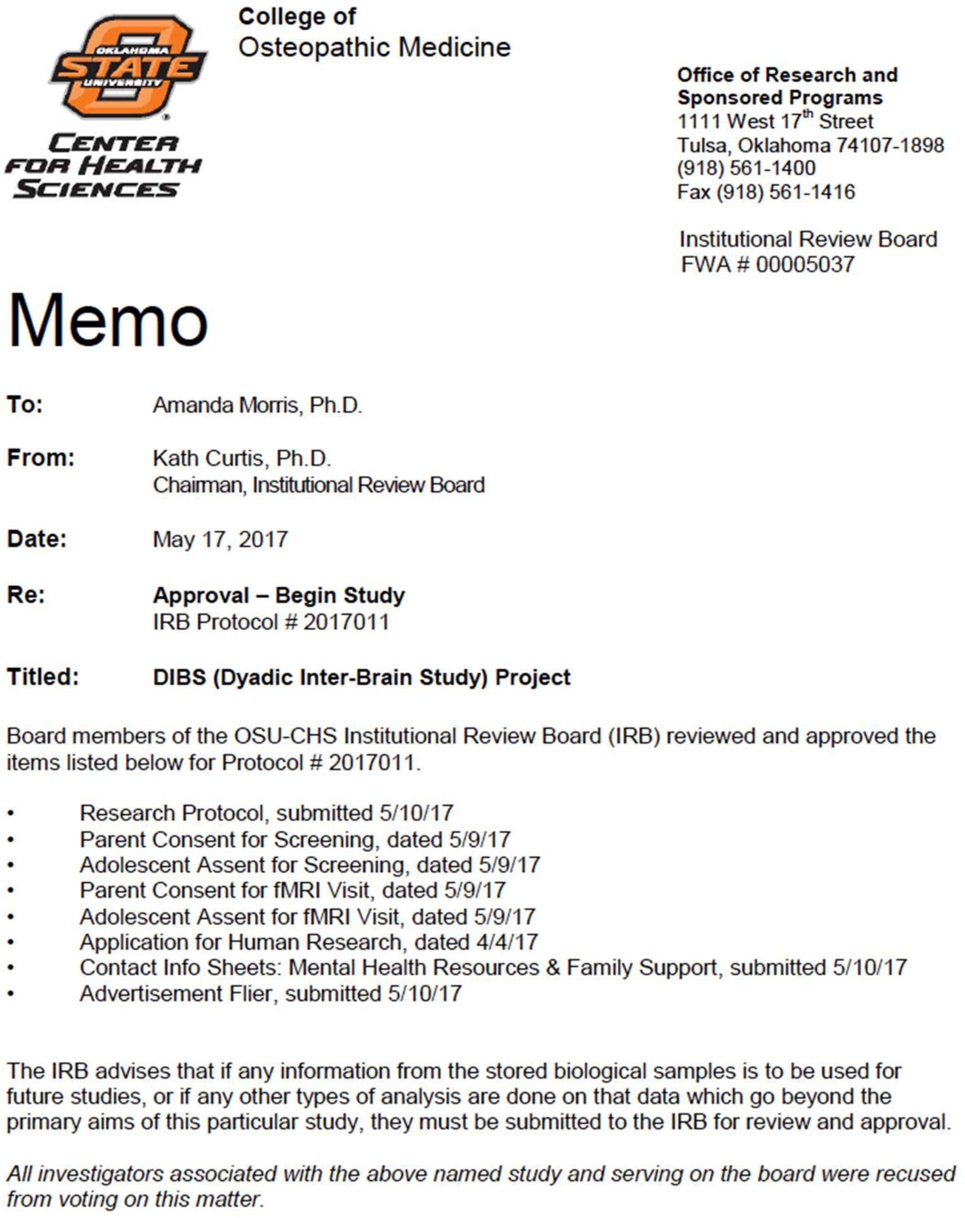
APPENDICES



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Institutional Review Board
FWA # 00005037

Memo

To: Amanda Morris, Ph.D.

From: Kath Curtis, Ph.D.
Chairman, Institutional Review Board

Date: May 17, 2017

Re: **Approval – Begin Study**
IRB Protocol # 2017011

Titled: **DIBS (Dyadic Inter-Brain Study) Project**

Board members of the OSU-CHS Institutional Review Board (IRB) reviewed and approved the items listed below for Protocol # 2017011.

- Research Protocol, submitted 5/10/17
- Parent Consent for Screening, dated 5/9/17
- Adolescent Assent for Screening, dated 5/9/17
- Parent Consent for fMRI Visit, dated 5/9/17
- Adolescent Assent for fMRI Visit, dated 5/9/17
- Application for Human Research, dated 4/4/17
- Contact Info Sheets: Mental Health Resources & Family Support, submitted 5/10/17
- Advertisement Flier, submitted 5/10/17

The IRB advises that if any information from the stored biological samples is to be used for future studies, or if any other types of analysis are done on that data which go beyond the primary aims of this particular study, they must be submitted to the IRB for review and approval.

All investigators associated with the above named study and serving on the board were recused from voting on this matter.

As principal investigator it is your responsibility to assure:

- The research is conducted in accordance with the IRB-approved protocol, including, when applicable, the approved recruitment and consent procedures;
- When informed consent is required, informed consent is obtained prior to the initiation of any study-related procedures;
- When written informed consent is required, informed consent is obtained and documented using the current IRB-stamped approved research consent form;
- Changes to the IRB-approved protocol and/or the research consent form are not initiated without prospective IRB approval unless necessary to eliminate apparent immediate hazards to the subject;
- Unanticipated problems involving risks to subjects or others (including adverse events) are reported promptly to the IRB in accordance with IRB policy. When reporting use the **"Reportable New Information Form"** found at www.healthsciences.okstate.edu/research/irb/forms.php.
- Adequate and accurate research records are kept and retained for three (3) years after termination of the study.

Continuing review must be conducted prior to expiration of IRB approval. When the research has been completed or is being closed out prior to completion, a final continuing review report is submitted to the IRB. When reporting use the **"Continuing Review or Study Completion"** form found at www.healthsciences.okstate.edu/research/irb/forms.php.

This study is approved for 12 months. ***An annual review for this Protocol will be due before May 16, 2018.***

If you have questions please contact Amber Hood, IRB Administrator, at 918-561-1413 or amber.hood@okstate.edu.

TABLES

Table 1. Example coded statements.

Positive Coding		Negative Coding	
Validation	“I think y’all are pretty special”	Disagree	“Your room is far from clean”
Agree	“I think that’s a good idea.”	Put Down	“This is all your fault”
Humor	“Kick all the kids out.”	Derisive Humor	“When I am ready, you decide to clean the entire house. You want to cut the grass. You want to check the mail.”
Elicit Opinion	“What can we do to solve that problem?”	Coerce	“Solve this problem by putting you in the corner."
Offer Solution	“I could set some sort of reminder on my phone”	Interrupt	“No, no, no, no, no.”
		Stonewall	“Nope it’s all my fault. You get to ride the bus from now on.”

Table 2. Pearson correlations between survey measures

	1	2	3	4	5	6
1. Parent Positivity		0.59**	0.92**	-0.18	-0.13	0.24
2. Adolescent Positivity			0.80**	-0.21	-0.30	0.33
3. Dyad Positivity				-0.24	-0.31	-0.28
4. DERS Total					0.52**	-0.48*
5. MFQ						-0.31
6. APQ Involvement						
M	0.70	0.70	0.68	68	5	61
SD	0.22	0.34	0.24	17	5	12

Note. DERS Total = Difficulties in Emotion Regulation total score. MFQ = Mood and Feelings Questionnaire. APQ Involvement = Alabama Parenting Questionnaire involvement subscale.

p < .05* *p* <.001**

Table 3. Cross-correlations between adolescent seed region and parent whole brain

				MNI Coordinates			
Adolescent Seed Region	**Parent Region**	**Condition**	**Vol (mm^3)**	**x**	**y**	**z**	**t value**
Positive Lag: Parent → Adolescent							
R Ant. Ins.	Bilateral med. frontal gyrus	Describe	1728	-3	39	37	5.39
R Ant. Ins.	R mid. frontal gyrus	Describe	672	45	25	33	4.72
L amygdala	R thalamus	Solution	544	19	-19	11	-4.65
L Ant. Ins.	L postcentral gyrus	Solution	856	-27	-29	65	-4.8
R Ant. Ins.	R mid. Occipital gyrus	Solution	968	31	-95	-5	-6.06
Negative Lag: Adolescent → Parent							
R Ant. Ins.	R mid. Occipital gyrus	Solution	712	-1	-75	49	5.31

Note. Ant. Ins. = anterior insula. med = medial. mid = middle. R = right hemisphere. L = left hemisphere. Vol = Volume in cubic millimeters. MNI coordinates and t value reflect the area of peak activation in the cluster.

Table 4. Cross-correlations between parent seed region and adolescent whole brain

				MNI Coordinates			
Parent Seed Region	**Adolescent Region**	**Condition**	**Vol (mm^3)**	**x**	**y**	**z**	**t value**
Positive Lag: Parent → Adolescent							
L amygdala	L precentral gyrus	Describe	800	-53	7	47	4.82
L amygdala	L post cingulate	Describe	560	-7	-49	7	5.55
L Ant. Ins.	R mid. temporal gyrus	Describe	608	47	-71	21	5.07
R Ant. Ins.	R mid. occipital gyrus	Describe	4064	45	-81	3	6.5
R Ant. Ins.	R mid. temporal gyrus	Describe	608	33	-73	23	4.51
R Ant. Ins.	R inf. occipital gyrus	Describe	592	43	-79	-13	4.69
L Ant. Ins.	Bilateral precuneus	Solution	608	1	-67	55	4.74
L Ant. Ins.	Bilateral post cingulate	Solution	512	-1	-41	9	4.88
R dlPFC	R postcentral gyrus	Solution	800	57	-21	43	-5.23
Negative Lag: Adolescent → Parent							
L dlPFC	R dACC	Describe	752	9	-31	-39	4.67
L dlPFC	R sup. frontal gyrus	Describe	584	3	33	53	4.91
L Ant. Ins.	R dACC	Describe	656	5	-21	43	4.48

Note. Ant. Ins. = anterior insula. dlPFC = dorsolaterial prefrontal cortex. med = medial. mid = middle. inf = inferior. Post = posterior. R = right hemisphere. L = left hemisphere. Vol = Volume in cubic millimeters. MNI coordinates and t value reflect the area of peak activation in the cluster.

FIGURES

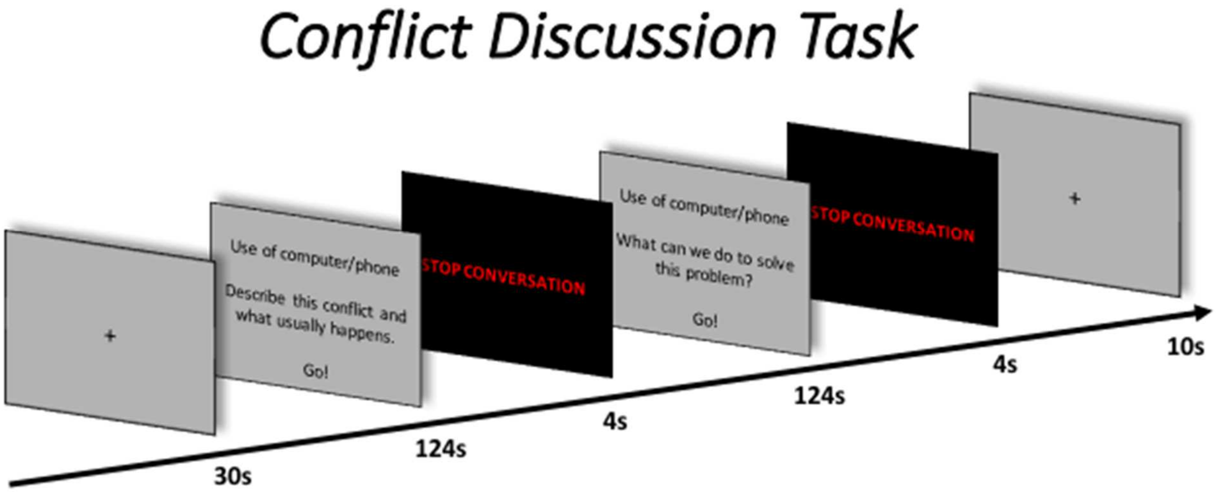

Figure 1. Conflict Discussion Task completed by parent and adolescent during fMRI hyperscanning.

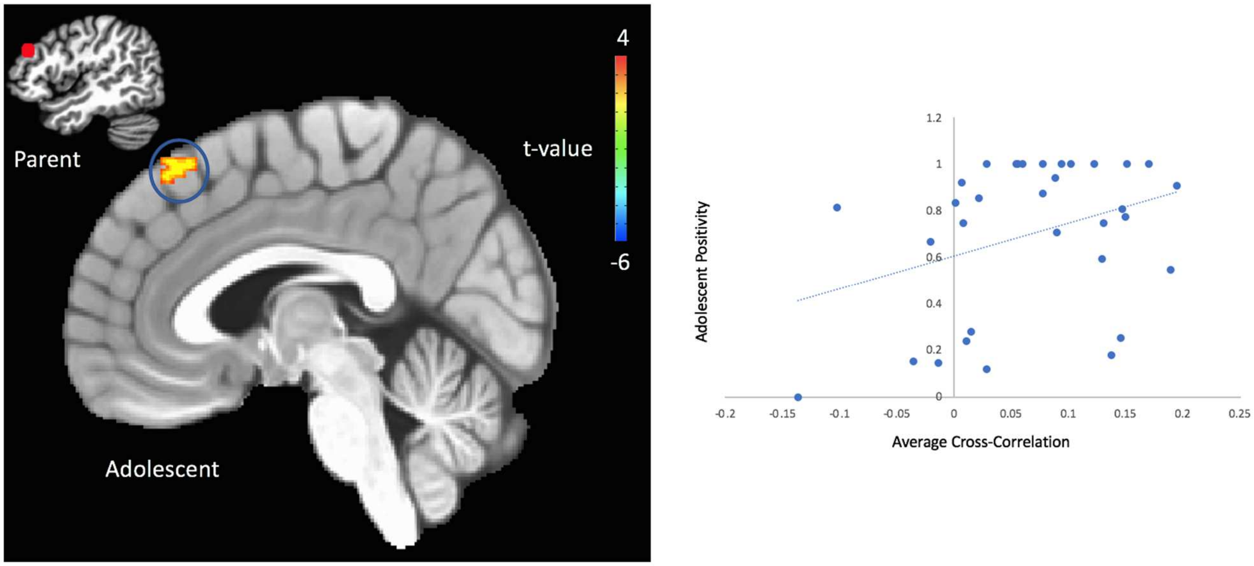

Figure 2. Results from analyses examining cross-brain connectivity between the parent left dlPFC seed region and the adolescent right superior frontal gyrus. Cross-brain connectivity between regions was significantly and positively correlated with adolescent positivity during the describe block of the Conflict Discussion Task.

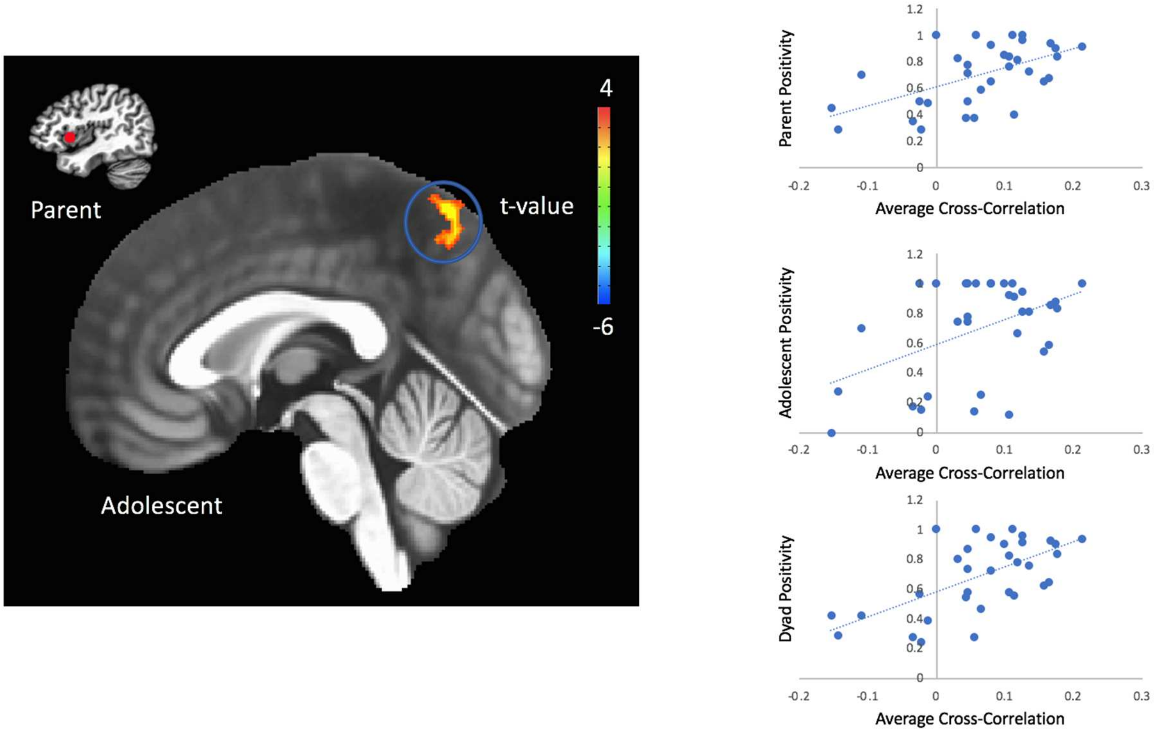

Figure 3. Results from analyses examining cross-brain connectivity between the parent left anterior insula seed region and the adolescent right precuneus. Cross-brain connectivity between regions was significantly and positively associated with parent positivity, adolescent positivity, and overall dyad positivity during the solution block of the Conflict Discussion Task.

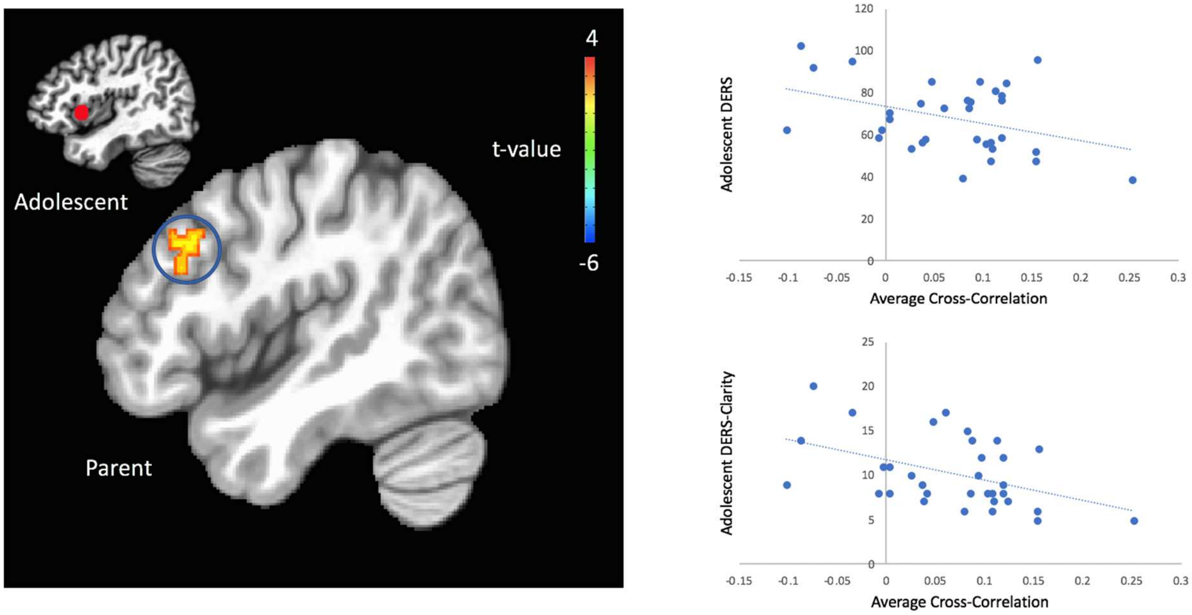

Figure 4. Results from analyses examining cross-brain connectivity between the adolescent right anterior insula seed region and the parent right middle frontal gyrus. Cross-brain connectivity between regions was significantly and negatively correlated with adolescent-reported DERS and the emotional clarity subscale of the DERS during the describe block of the Conflict Discussion Task.

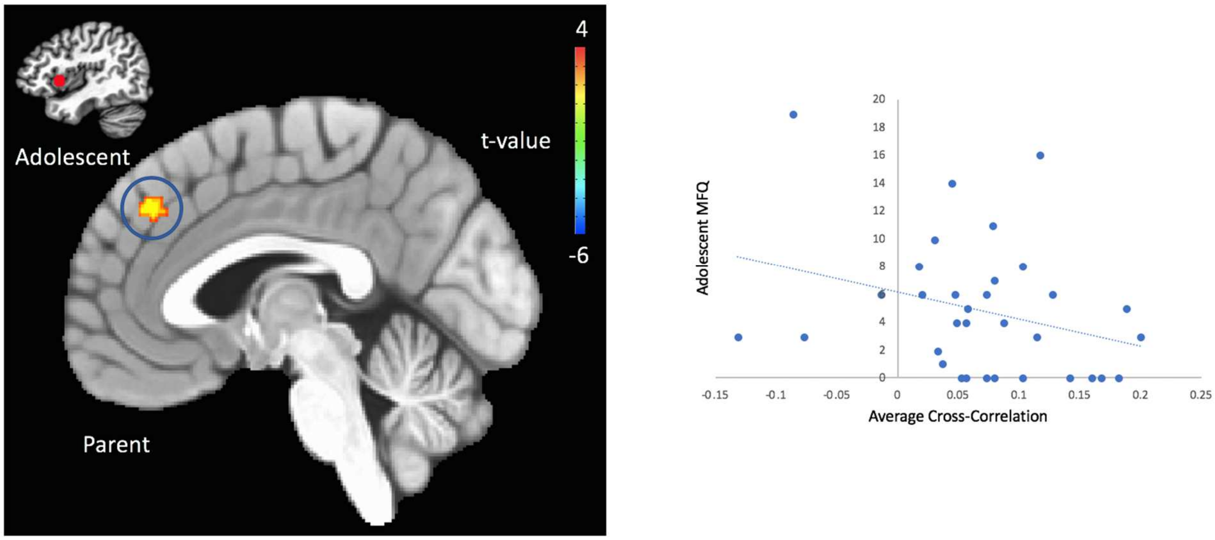

Figure 5. Results from analyses examining cross-brain connectivity between the adolescent right anterior insula seed region and the parent right medial frontal gyrus. Cross-brain connectivity between regions was significantly and negatively correlated with adolescent-reported MFQ during the describe block of the Conflict Discussion Task.

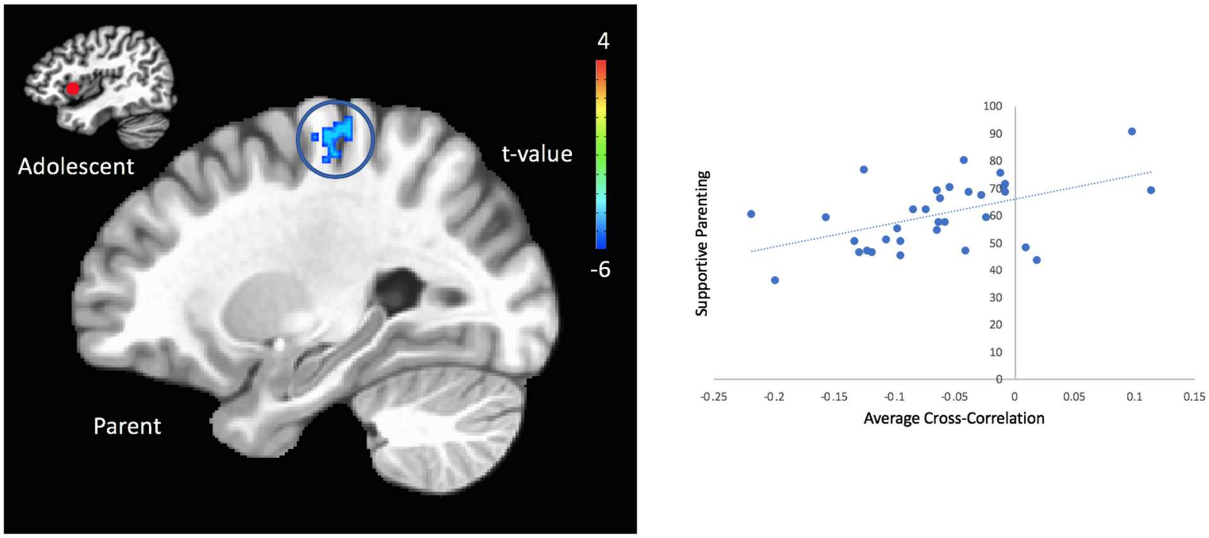

Figure 6. Results from analyses examining cross-brain connectivity between the adolescent left anterior insula seed region and the parent left postcentral gyrus. Cross-brain connectivity between these regions was significantly and positively correlated with adolescent-reported supportive parenting during the solution block of the Conflict Discussion Task.

VITA

Erin L. Ratliff

Candidate for the Degree of

Master of Science

Thesis: THE ROLE OF CROSS-BRAIN CONNECTIVITY IN EMOTION REGULATION WITHIN THE PARENT-ADOLESCENT DYAD

Major Field: Human Development and Family Science

Biographical:

Education:

Completed the requirements for the Master of Science in Human Development and Family Science at Oklahoma State University, Stillwater, Oklahoma in July, 2019.

Completed the requirements for the Bachelor of Science in Psychology at Mansfield University, Mansfield, Pennsylvania in 2015.

Experience:

Aug. 2017 - Present:

Dyadic Inter-Brain Signaling (DIBS) Study
Graduate Research Assistant, Laureate Institute for Brain Research
Responsibilities include:

- Recruitment and scheduling participants
- Administration of cognitive tasks during fMRI scan
- Collection of EEG, behavioral, and metabolic data using fMRI hyper scanning technology during parent-child interactions
- fMRI data analysis using AFNI and R

Professional Memberships:

2018 - Present: Society for Research in Child Development
2012 - Present: Psi Chi, International Honor Society in Psychology