Title

The Neural Correlates of Empathy that Predict Prosocial Behavior in Adolescence

Author

Lazar, Lee

Publication Date

2023

UNIVERSITY OF CALIFORNIA

Los Angeles

The Neural Correlates of Empathy that Predict Prosocial Behavior in Adolescence

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Psychology

by

Lee Lazar

2023

ABSTRACT OF THE DISSERTATION

The Neural Correlates of Empathy that Predict Prosocial Behavior in Adolescence

by

Lee Lazar

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2023

Professor Naomi Ilana Eisenberger, Chair

Empathy has been commonly referred to as a catalyst for prosocial behavior (i.e. helping). However, empathy does not always compel one to act in a supportive or helpful manner. This is because empathy is a complex, multidimensional construct which can involve the sharing of emotions with another (an affective process), taking the perspective of another (a cognitive process), and feeling sorrow or concern for another (prosocial concern), features which interact and promote prosocial behavior in varying ways depending on the situation. Neuroscience methods have allowed researchers to examine the neural correlates of these components as individuals undergo an empathic experience. Interestingly, there is evidence that the components of empathy have dissociable neural correlates with differing developmental trajectories. Importantly, neural regions underlying the cognitive component of empathy continue to undergo structural and functional change throughout adolescence, making it a particularly critical stage to investigate how empathy develops and relates to prosocial behavior. Thus, in the present study, 11–17-year-olds viewed the social exclusion of a same-aged peer (Cyberball) as they underwent a functional magnetic resonance imaging (fMRI) scan. After exiting the scanner, participants were given the opportunity to write messages to both the victim and excluders who played in the Cyberball game. Participants' neural activity in Affective Pain (dACC, AI), Mentalizing (pSTS, dmPFC, TPJ), and Prosocial Concern (SA, mOFC) networks while viewing the exclusion (vs inclusion) were extracted and examined in relation to the degree of prosocial behavior participants displayed after the scan. Results revealed gender differences in both state empathy and prosocial behavior in response to viewing the social exclusion, such that girls reported feeling greater empathy for the victim of the exclusion. Affective Pain and Mentalizing networks both showed significant activation across the whole sample when viewing the exclusion episode compared to inclusion, though girls showed significantly greater activity in the Mentalizing network compared to boys. Additionally, there were significant gender differences in how trait perspective taking related to activation in the Affective Pain network during exclusion. In terms of how neural activity predicts subsequent prosocial behavior, the Prosocial Concern network was the only network to relate to prosocial behavior, such that older adolescents (15 to 17-year-olds) showed a significant positive relationship between Prosocial Concern network activity during exclusion and subsequent prosocial behavior. Results suggest important gender differences to consider in understanding empathy and prosocial behavior in adolescence, and reveal that the Prosocial Concern network is uniquely predictive of prosocial behavior amongst older adolescents. The Prosocial Concern network includes neural regions involved in the evolved mammalian and human caregiving systems. Thus, this may suggest that older adolescents have a more mature or developed caregiving system (aligning with the age in which they can physically reproduce), which can be used to support prosocial behavior.

The dissertation of Lee Lazar is approved.

Andrew J. Fuligni

Adriana Galván

Jennifer Ashley Silvers

Naomi Ilana Eisenberger, Committee Chair

University of California, Los Angeles

2023

Table of Contents

List of Tables

List of Figures

Acknowledgements

The acknowledgements section of my dissertation is simultaneously one of the clearest yet most challenging pieces of writing I have had to complete in graduate school. Clearest because thinking of those who have helped me get to this moment is not a difficult task – I am constantly reflecting on how lucky I am to have them. It is, however, the most challenging because it feels like an impossible task to capture the overwhelming sense of gratitude I have for the many that have carried me to this point, and to translate that feeling into words that do it justice. However, I will write as much as I think readers will have patience for, in hopes that the weight of my emotions will be relayed somehow.

In the beginning of the pandemic, as we started getting used to communicating with one another via zoom in our respective places of isolation, I watched endless touching commercials and videos of people helping and supporting one another through the “unprecedented times”. As I sit there, feeling so uplifted with a face full of tears, I became interested in this feeling that I discovered was otherwise referred to as “kama muta”, Sanskrit for “moved by love”. Most people that know me know it doesn’t take much for me to experience kama muta – a beautiful song, a sweet video, or even the beginning scenes the movie Up can bring me to tears. But when life slowed down and topics we studied in our lab on social connection and isolation took center-stage in the world, I brought this idea of studying “kama muta” to my advisor, Naomi Eisenberger. Not only was Naomi open to going on this journey with me, but we spent hours upon hours discussing this and sending articles back and forth (and I should note, most of this was out of pure interest and curiosity). This is just a small example of the many things we’ve spent weeks, months, or even years discussing, but I think it encapsulates the type of advisor Naomi is. She is incredibly thoughtful, caring, and I have always felt that she wanted what was

truly best for me, not only by letting me explore topics that interested me in the moment, but exploring them with me and guiding me throughout. One of my favorite parts of graduate school has been our weekly meetings, as they have been what I imagined a PhD to be like when I was little – an incredibly stimulating both academic and personal conversation, discussing abstract concepts but distilling them down into something measurable. I've left each meeting feeling curious, inspired, and in awe of the way Naomi thinks.

While graduate school felt incredibly daunting at times and I came in feeling clueless, from day one Naomi has made me feel comfortable asking her questions big and small, however silly I am sure they were in the moment. I quickly understood why everyone had been stressing the importance of a graduate student's relationship with their advisor, because it is largely because of Naomi that I have gotten through this PhD and had such an enlightening and positive experience. Thank you, Naomi, for supporting me not just as a student, but as an individual. You truly personify everything you study.

Another immense thank you is owed to my dissertation committee members, Andrew Fuligni, Adriana Galván, and Jennifer Silvers, who have been incredible mentors and teachers as I entered the world of Developmental Neuroscience. I feel incredibly lucky to have had the opportunity to both work with and learn from such intelligent, creative, and thoughtful individuals, who are not only leaders in this field, but clearly have a passion for the translation and use of their work. This is, in my opinion, most admirable of a successful scholar. I would also like to give a big thank you to members of the Social and Affective Neuroscience (SAN) lab who have joined or graduated throughout my time at UCLA – I believe there is something truly special about those who devote so much time to studying the topics in this lab, and I am so grateful for the wisdom, support, and advice I constantly received as I "data dumped" in several meetings, along with the many times I have learned from all the interesting work each one of you is doing. A special thank you to Carrie Leschak who has single-handedly taught me neuroimaging analyses (along with many other things) and has been consistently such a patient, thoughtful, and organized mentor. You have taught me more than I can express, and I am incredibly thankful for your guidance these past 5 years.

To Maira, who became my partner-in-crime in research along with a true friend. Working with you has been one of the best parts of graduate school, and I am beyond grateful that research has brought us together. We fell into such a seamless and natural partnership, where we somehow easily understood how to support one another through the ups and downs of the past few years. Graduate school has felt a lot more manageable with you by my side. To my cohort-mates – I am so glad the pandemic only brought us closer, and I cherish all the fun times we've had around LA together. Nick Ichien, I'm so glad we got put in the same office first year. Our Monday night dinners and café study sessions got me through some hard times. Ryan Hyon, thank you for continuing to be a sounding board for all my crazy thoughts and ideas, and I'm so grateful we got to live together in San Francisco.

I was also blessed with incredible mentors that helped me expand my thinking and skills beyond the scope of my scientific research. To Yalda Uhls, who I've seen grow an incredible business throughout the past 5 years. Thank you for helping me broaden my horizons and for providing me with invaluable opportunities that have been instrumental in my development as a researcher and science-communicator. Thank you to Noah Goldstein - I came to you as a wide-eyed first year graduate student who simply loved your research and was fascinated by persuasion, and your faith in me as a teaching assistant (of MBA students I was slightly intimidated by) has been empowering. The way you teach students is both inspirational and an absolute pleasure to watch. Of course, your comedic relief is always greatly appreciated as well.

I would be remiss not to include the funding sources that have generously supported both me and my research throughout the past 5 years, which include the UCLA Graduate Division, Bedari Kindness Institute, and National Institute of Child Health and Human Development T32 training program.

Finally, I owe all my successes to my family, who have been a continual source of unwavering emotional, physical, and financial support both during my PhD and beyond. To my parents, who have not only encouraged me to follow my dreams and seek growth and greatness but have pushed me towards it. I am aware that this type of love and dedication from parents can be rare, and I treasure the fact that I have you. Abba – stepping foot into the house after a long week and being greeted by you racing to the door, arms open wide and face grinning from ear to ear with a big smile is enough to melt any fear or anxiety away. Thank you for showing me how trivial most worries are, for continuing to teach me invaluable life lessons, and for showing me that we should always enjoy each step of the way. Your zest for life is infectious, and I am honored to be your daughter. Ima – I would not have been inspired to pursue research let alone graduating from a PhD program if it wasn't for you. You wear so many hats for me, I can't seem to understand how one doesn't fall off – dedicated mother, role model, best friend, therapist, and professional worrier. We went through each stage of this program together, and I am adamant that you share in this accomplishment with me. Thank you for instilling in me a love of science and research, and then paving the way for me to pursue it as much as I possibly could. To my siblings, Aviv, Bar, and Gil – getting to grow up with such accomplished and dynamic older twin sisters to teach me, and then learning how to mirror that as I became a big sister to Gil, has been a privilege I will never take for granted. The differences between the four of us make every conversation and experience fun and interesting, and I feel so lucky to have grown up with you all. Even though you may not have always known what I was doing in grad school in each moment, I have always felt an underlying sense of calm knowing that I have my siblings no matter what, to talk through things if I need or completely distract me from it. You are my best friends, and I love you all. To my grandparents, who have been my cheerleaders and source of inspiration. Thank you for believing in me and encouraging me every step of the way.

And to Lipi, who has had to hear me ramble on about every little thing that enters my brain, whether that be a research idea, paper I read, insignificant story about something that happened to me that day, or thought I had in the shower. Thank you for always listening so intently (even when it’s not so interesting) and for being your level-headed and reliable self. Your passion for learning and growth has been such a beautiful reminder for me to reflect on how grateful I am to have been able to dedicate myself to that over the past 5 years. Finally, to me friends, whether that be from childhood, high school, college, or life in general – you know who you are and fill my life with so much joy. Thank you for always being there.

Vita

Education

2018	M.A., Psychology; University of California, Los Angeles
2017	B.A., Psychology, Minor Disabilities Studies *Magna Cum Laude*; University of California, Berkeley

Selected Funding

2022-2023	Dissertation Year Fellowship, UCLA
2021-2022	NIH National Research Service Award (NRSA), T32 Predoctoral Fellowship
2022	Graduate Fellowship, Bedari Kindness Institute
2020-2021	Graduate Research Mentorship Award, UCLA
2020	Summer Graduate Fellowship, Bedari Kindness Institute
2018	Graduate Summer Research Mentorship Award, UCLA

Publications

* Indicates equal contribution

Lazar, L., & Eisenberger, N. I. (2022). The benefits of giving: Effects of prosocial behavior on recovery from stress. *Psychophysiology, 59*(2), e13954.

Karan, M.*, **Lazar, L.*,** Leschak, C. J., Galván, A., Eisenberger, N. I., Uy, J. P., ... & Fuligni, A. J. (2022). Giving to others and neural processing during adolescence. *Developmental Cognitive Neuroscience*, *56*, 101128.

Riewestahl, E. L., **Lazar, L.,** Rivas-Lara, S. A., & Uhls, Y. T. (2023). Beyond the ivory tower to the silver screen: promoting positive development in children and adolescents through outreach to content creators. *The Journal of Positive Psychology*, 1-11.

Hornstein, E., **Lazar, L.,** Eisenberger, N. (2023) The effect of loneliness on evaluative fear extinction.*Nature Human Behavior.* (in prep)

Lazar, L., Hornstein, E., Eisenberger, N. (2023) The psychological effects of an acts of kindness intervention. (in prep)

Presentations & Talks

Talks

The Neural Correlates of Empathy to Predict Prosocial Behavior Across Adolescent Development

Invited talk presented at the Brain & Behavioral Development During Adolescence (BBDA) Lecture Series, UCLA. (2021, June) (2022, March)

UCLA Leading the Way: Impacting Diversity, Equity, and Inclusion (DEI) in Hollywood

Moderated special virtual event at UCLA on DEI in Hollywood (2021, October)

Character Conference: CSS Think Tank

Led and facilitated think tank at the Character Interventions Conference on promoting character virtues in children and adolescents through entertainment media (2021, August)

The benefits of giving: Effects of prosocial behavior on recovery from stress

Social Area Forum, UCLA (2020, June)

Poster Presentations

Karan, M.*, **Lazar, L.*,** Leschak, C., Dieffenbach, M., Crone, E., Eisenberger, N., Galván, A., Telzer, E., Uy, J., Fuligni, A. (2021, April). *Giving to Others and Neural Processing During Adolescence*. Poster presented at Annual Meeting of the Social and Affective Neuroscience Society (SANS), virtual.

Karan, M.*, **Lazar, L.*,** Leschak, C., Dieffenbach, M., Crone, E., Eisenberger, N., Galván, A., Telzer, E., Uy, J., Fuligni, A. (2020, September). *Giving to Others During Adolescence (Behavioral Results*). Poster presented at the Flux Congress, The Society for Developmental Cognitive Neuroscience, virtual.

Selected Teaching Positions

2022/2021/2020	Teaching Associate, Persuasion & Influence, UCLA (MBA)
2021	Teaching Associate, Leadership Foundations, UCLA (MBA)
2019	Teaching Assistant, Social Psychology, UCLA
2018	Teaching Assistant, Introduction to Psychology, UCLA
2015	Undergraduate Instructor, Behavioral Epigenetics, UC Berkeley

The Neural Correlates of Empathy to Predict Prosocial Behavior in Adolescence

I. Background

Empathy, considered the ability to understand, feel, and share in the emotions of another, is at the core of the human experience, allowing individuals to connect with each other on an emotional level. Given empathy's role in the formation of social and emotional bonds, it has been a frequently proposed predictor or motivator of prosocial behavior (Decety & Cowell, 2014; Lockwood, 2016). However, more recent work on empathy and its links to prosocial behavior has challenged this idea, underscoring the lack of support for the basic assumption that empathy, as it has been more traditionally measured, is a predictor of prosocial behavior (Decety & Yoder, 2016; Jordan et al., 2016; Stevens & Taber, 2021; Vachon et al., 2014). Understanding or feeling what another person is feeling may not be enough to inspire action, but by decomposing and understanding the multifaceted, broad spectrum of events that can make up an empathic experience, research can begin to shed light on when empathy is indeed related to or an antecedent of prosocial behavior.

Empathy is a complex construct which involves several components that interact in various ways, through both bottom-up and top-down processes (Decety & Jackson, 2004; Shamay-Tsoory, 2011; Tousignant et al., 2017). Bottom-up mechanisms of empathy involve the more basic processing of sensory inputs that respond to another's pain by mirroring that pain in oneself (i.e. affect or experience sharing). Top-down mechanisms, on the other hand, involve higher level cognitive processing such as taking the perspective of another person to understand how they feel (Tousignant et al., 2017). Although scholars across the fields of social psychology, developmental psychology, and neuroscience may differ in how they define and classify empathy, there is general agreement that, in a broader sense, these bottom-up and top-down processes can be categorized into affective and cognitive components of empathy, and that these components differ conceptually, behaviorally, within the brain, and may align with prosocial behavior in a different way across development (Eisenberg et al., 2006; Winters et al., 2021). While there is general agreement that empathy involves affective and cognitive components which rely on distinct brain regions (Shamay-Tsoory et al., 2004), the literature becomes mixed when determining how to understand prosocial or empathic concern, defined as the feeling of sorrow or concern for another (Hall & Schwartz, 2019; Stevens & Taber, 2021). While some consider prosocial concern to be a part of affective empathy (Fabi et al., 2019; Israelashvili et al., 2020), others include it as a third primary component within their conceptualization of empathy (Morelli et al., 2014; Ochsner, 2013; Zaki & Ochsner, 2012). Given that prosocial concern is most often associated with and predictive of prosocial behavior, both in self-reported trait empathic concern (Batson, 2012) and its associated neural correlates (Ashar et al., 2017; FeldmanHall et al., 2015), it was important for the current investigation to both include and methodologically define and measure this component of empathy to help clarify the relationship between empathy and prosociality. Given the importance of promoting prosocial behavior within society (Aknin et al., 2015), it is critical to understand when and how empathy can serve as a motivator for helping behavior, as it provides researchers with a better understanding of what aspects of empathy should be trained and nurtured.

The Importance of Investigating Empathy in Adolescence

An optimal time for both investigating empathy and targeting empathy-training is in adolescence. Adolescence, the period of life between puberty and the achievement of full independence, is marked by great physical, social, behavioral, and cognitive changes (Blakemore & Mills, 2014). In fact, it is arguably the most pivotal transition period of one’s life for developing into a socially competent adult, and a formative period for empathy development. Importantly, regions of the brain that underlie socioemotional and cognitive processing have been shown to develop at different rates throughout adolescence, such that the socioemotional system develops earlier than cognitive control, which is a key factor in characterizing it as time of great malleability and change (Blakemore, 2012; Blakemore & Mills, 2014; Crone & Dahl, 2012). So, while the ability and tendency to experience affective empathy may be present as early as infancy, adolescence is marked by a gradually strengthening ability to take on another person's point of view, a skill that continues to develop into late adolescence likely due to improvements in cognitive regions of the brain (Kilford et al., 2016). Given the neural changes that underlie perspective taking throughout adolescence, it is likely that the components that make up an empathic experience and subsequently predict prosocial behavior may evolve throughout adolescence and into adulthood. Thus, understanding how the neural regions involved in empathy are altered throughout adolescence allows researchers to gain greater insight into how empathy itself develops. Additionally, there has been less work investigating how the neural correlates underlying empathic concern might develop or mature throughout adolescence, and how it may differentially relate to prosocial behavior.

Thus, understanding empathy and its relation to prosocial behavior across adolescence is critical to investigate, given both the importance empathy has in building peer relationships, which is a central aspect of well-being in adolescence (Mella et al., 2012), and the long-term effects increases in empathy during adolescence can have in adulthood, such better integration in adult social networks (Allemand et al., 2015).

Components of Empathy

Including empathic concern as a central component of empathy, the current investigation conceptualizes empathy in 3 main components: (i) affective empathy (affect or experience sharing), (ii) cognitive empathy (perspective taking or mentalizing), and (iii) prosocial concern (empathic care or concern). While these components are dissociable and have been discussed and investigated as such, it is important to note that mature empathic responding often relies on a functional integration of these components to promote goal-directed social behavior (Decety, 2010).

Affective Empathy

Affective empathy is often described as the most basic form of empathy, characterized by the sharing or simulation of another's affective experience, vicariously experiencing their internal states (Ashar et al., 2017; Morelli et al., 2014; Zaki & Ochsner, 2012). Thus, affective empathy makes up the bottom-up process of empathy, which has been discussed in the context of affective resonance (Decety & Meyer, 2008), affective arousal (Decety, 2010), emotional contagion (Shamay-Tsoory, 2011), and shared representations between self and other (Decety & Jackson, 2004). Researchers began investigating affective empathy by examining what's thought to be its most basic form, defined as unconscious automatic mimicry. The concept of unconscious automatic mimicry (emotional mimicry) came from the idea that the autonomic nervous system of a member of one species is genetically programmed to respond to an affective expression in another member of the same species, by generating a mirrored or similar response (Basch, 1983; Decety & Lamm, 2009). Per this view, perceiving a target's facial or bodily state will automatically trigger an unconscious somatic or autonomic response of that same state in the observer. This view has been supported by research on sensorimotor neurons (mirror neurons) in the premotor and posterior parietal cortex, which have been shown to be associated with both the production of an action and the perception of that same action performed by another individual (Decety, 2011; Preston & De Waal, 2002). Thus, researchers tend to view this as the most basic reaction one can have to the affective state of another, and some have even redefined emotional mimicry as ‘motor empathy’, when mirroring of another’s bodily state, facial expressions, or gestures occurs automatically (Blair, 2005; Reniers et al., 2011; Walter, 2012). Whether emotional mimicry involves the actual sharing of another’s emotions has been up for debate, as some scholars have argued that this is merely a matching of nonverbal emotional displays rather than the experience of that emotion itself (Hess & Fischer, 2014). However, emotional mimicry and contagion may still hold an important role in laying the foundation for affective empathy, which involves not just a mimicking of nonverbal expressions, but a mirroring of affective states as well (Lamm et al., 2011; Singer & Lamm, 2009).

Neural Correlates of Affective Empathy

A majority of early neuroimaging work on empathy has focused on the observation of physical pain in others, and consistently found recruitment of regions involved in the affective experience of first-hand pain, the dorsal anterior cingulate cortex (dACC) and anterior insula (AI), when viewing another person undergoing physical pain (Fan et al., 2011; Jackson et al., 2005; Lamm et al., 2011; Singer & Frith, 2005). This overlap of self and other related pain regions has also been shown in response to other aversive affective states as well, as Wicker and colleagues (2003) found that both the first-hand experience of disgust and the sight of a disgusted facial expression in another person corresponded with activation in the anterior insula. Additionally, neural regions related to affective empathy have not only been shown to be present when experiencing empathy for adverse affective states like pain but have also been shown to relate to empathy for positive emotions as well. Morelli, Rameson and Lieberman (2014) showed how affective congruence does not always correspond with activation in the affective pain-related regions of the dACC and AI, but relate to the specific emotion the observer is empathizing with. As such, they found that empathizing with a target's positive emotion did not involve activation in the dACC and AI, but rather the ventromedial prefrontal cortex (VMPFC), a region associated with the first-hand experience of positive affect. Thus, affective empathy represents a matching to the affective state of the target, whether that be positive or negative.

However, affective pain related neural responding has not only been shown when empathizing with a viscerally, physically painful image, but has also been observed when empathizing with another's social pain, such as observing a social exclusion. Although witnessing the social exclusion of another has been more frequently associated with activation in the mentalizing network rather than the affective pain network (see Neural Correlates of Cognitive Empathy below for review), viewing the exclusion of a close friend has been shown to involve activation in both mentalizing and affective pain regions (dACC and AI) (Meyer et al., 2013). Additionally, those scoring high in trait empathy also showed significant activation in the dACC and AI when viewing a social exclusion, even when the social exclusion was of a stranger (Masten et al., 2011). These studies used a classical social pain paradigm (Cyberball; Williams et al., 2000), which requires the participant to deliberately take the perspective of the victim of exclusion to understand their mental states and potentially trigger an emotional response (Eisenberger, 2012).

Cognitive Empathy

While empathy can be driven by bottom-up, automatic processes that contribute to forming shared emotional meanings, a top-down, higher-order process referred to as mentalizing or perspective taking is another important facet of empathy, making up the cognitive component of empathy (Decety, 2010; Tousignant et al., 2017). This top-down process involves actively taking the perspective of another to understand their internal state (perspective taking), whether the empathizer is sharing the affective state themselves or not. Perspective taking requires an individual to imagine what the other person is feeling or experiencing to understand that they are feeling, and has only been found in more phylogenetically advanced mammals (De Waal, 2007). Thus, it is possible for one to empathize with another without sharing their affective state, but rather by taking steps to understand it (Ruby & Decety, 2004; Walter, 2012). Models of empathy which include these top-down processes emphasize the malleability of an empathic experience, which may vary by the type of situation in which the social interaction occurs (Lamm et al., 2007).

Neural Correlates of Cognitive Empathy

Much neuroimaging research investigating the top-down process of cognitive empathy have explicitly instructed participants to imagine another's pain or take the perspective of someone experiencing pain to examine associated neural responding (Decety & Grèzes, 2006). For example, in one study by Ruby and Decety (2004), participants listened to emotionally evocative vignettes while undergoing an fMRI scan but were explicitly instructed to imagine how the individual in the vignette is feeling. By instructing participants to actively take the target's perspective, they found associated activation in regions of the prefrontal cortex associated with mentalizing and perspective taking, like the TPJ. Perspective taking can also serve a modulating role on affect sharing, depending upon the situation at hand. For example, studies have shown that participants instructed to take a self-perspective to painful stimuli exhibited activation in pain processing regions of the brain. However, when instructed to take the perspective of the target instead, participants showed greater activation in mentalizing neural regions (Jackson et al., 2006; Tousignant et al., 2017). This shows that the often-automatic affective response to a painful stimulus (such as seeing another person in pain) can be modulated or tampered down by top-down processes in which one actively takes the perspective of the other person rather than focusing on how it might feel for themselves.

While an initial affective response to pain may often be the basis of shared emotional meaning, reaching a cognitive understanding of another's emotion or experience allows for a more mature empathic response. However, perspective taking can also stand alone as a means of empathizing with another, particularly in research paradigms where there is no perceptual cue of distress and thus requires one to infer another's distress (such as viewing an episode of social exclusion; Masten et al., 2010, 2011). While studies that use picture-based paradigms provide a visual signal of pain or distress, abstract visual cues seem to require greater involvement of perspective taking abilities to fully empathize with another's suffering. Experiencing empathy for context-dependent situations like viewing an episode of social rejection or hearing about another's negative life event have shown to recruit regions of the brain involved in the mentalizing network, such as the dmPFC (Masten et al., 2010, 2011; Meyer et al., 2013; Zaki et al., 2009). Other regions frequently implicated in studies examining cognitive empathy (perspective taking) include the posterior superior temporal sulcus (pSTS) and temporoparietal junction (TPJ) (Lamm et al., 2011; Schnell et al., 2011; Singer et al., 2006).

Prosocial Concern

Whether referred to as prosocial concern, empathic care, empathic concern, altruistic motivation, sympathy, compassion, or prosocial motivation, scholars across various fields have recognized that this other-oriented emotion or motivation is either central or related to the experience of empathy—whether it is considered a proxy for affective empathy, a product of affective and/or cognitive empathy, a distinct phenomenon, or one of the core processes of empathy itself (Cuff et al., 2016; Hastings et al., 2013; Preston & De Waal, 2002; Stevens & Taber, 2021; Zaki & Ochsner, 2012). While there is disagreement in how empathy is defined, particularly in how to conceptualize prosocial concern, it is important to distinguish between the affective component of empathy here and empathic or prosocial concern, as prosocial concern relates specifically to the caring for another's state, rather than the sharing or understanding of it (Decety et al., 2015; Marsh, 2016). In the current work, prosocial concern is considered a third component of empathy, referring to an other-oriented, tender state experienced in response to another's distress, often coupled with the motivation to help the other relieve that distress (De Waal, 2008; Marsh, 2016; Zaki & Ochsner, 2012). While empathic concern (an interchangeable term for prosocial concern) has been measured through self-report using assessments like the Interpersonal Reactivity Index (IRI; Davis, 1983), this measure considers empathic concern as synonymous with the affective component of empathy. Thus, using the IRI, aspects specific to prosocial concern or empathic care can be conflated with the more basic process of affect sharing. However, neuroimaging work has clarified that empathic care (prosocial concern) is distinct from affective empathy in its neural correlates (Ashar et al., 2017), and has been more clearly tied to helping behavior (Batson, 2011; Eisenberg & Mussen, 1989).

Neural Correlates of Prosocial Concern

Advancements in drawing brain-behavior links in prosocial concern have not only allowed researchers to identify its associated neural correlates, but also uncover the neural predictors of prosocial behavior that seem to overlap with these correlates (Ashar et al., 2017; Zaki & Ochsner, 2012). A study by Ashar et al. (2017) aimed to characterize the neural markers of prosocial concern (using the term empathic care) by developing fMRI markers that predicted moment-to-moment, self-reported ratings of empathic care versus personal distress while participants listened to biographies of others’ suffering, and further used these markers to predict later charitable donation. They found empathic care to be specifically related to activation in the septal area, vmPFC, mOFC, and VS, and the empathic care marker to be a strong predictor of daily helping behaviors. Interestingly, Morelli et al. (2014) also found the septal area to be the only neural predictor of daily helping across different empathic experiences of pain, anxiety, and happiness. The septal area is a region of the brain commonly associated with maternal caregiving in animal models, and rats with lesions in the septal area have been shown to exhibit issues with maternal caregiving behaviors (Febo et al., 2005; Sheehan & Numan, 2000). Septal area activity has also been associated with affiliative behavior in humans, as studies have shown significant activity in the septal area when participants made charitable donations (compared to when they received a monetary reward for themselves; Moll et al., 2006). Additionally, individuals with septal damage have been shown to have an impairment in prosocial sentiments, such that the degree of impairment is associated with the degree of damage (Moll et al., 2011).

Thus, findings connecting neural responding during experiences of empathy to prosocial behavior would suggest that the neural regions distinctly associated with empathic care (prosocial concern) play a unique function in predicting prosocial behavior. Another neural region identified in the brain marker for empathic care by Ashar and colleagues (2017), aside from the septal area, was the mOFC. The mOFC has been frequently discussed in studies of compassion, which is closely related if not an interchangeable term with prosocial concern, and involves an intentional or conscious orientation toward the well-being of others (Hastings et al., 2013). Participants who underwent a short compassion training showed increased activation in the medial orbitofrontal cortex (mOFC) when viewing another’s distress, suggesting an important involvement of the mOFC in feelings of compassion (Klimecki et al., 2013). Activity in the mOFC has also been associated with both attachment and caregiving systems, as significant mOFC activity has been reported in mothers with secure attachments viewing images of their happy children (Strathearn et al., 2009) and has been associated with experiencing maternal love more generally (Bartels & Zeki, 2004). Additionally, mOFC activity has been shown to correspond with approach-related motivation in the human caregiving system (Rilling, 2013), and has been shown to be rapidly activated in response to pictures of newborns (even when they are unrelated newborns, compared to attractive adult faces; Kringelbach et al., 2008) and when human mothers hear infant cries (Lorberbaum et al., 1999).

Given the associations that both the septal area and mOFC have with the evolved mammalian and human parental caregiving systems, it is possible that prosocial motivation or empathic concern is a more generalized form of the parental nurturing response (Marsh, 2016; Marsh et al., 2014; Preston, 2013). Thus, viewing and feeling the fear and distress of another (mirroring infantile cues) might lead humans to respond to these infant-like cues using an innate caregiving response.

Development of Empathy

While the mechanisms for sharing the affect or experience of another have been shown to be hardwired and functional early on in life (Decety, 2010; Decety & Jackson, 2004) there is evidence that this process continues to be refined during childhood and into adolescence, given the ongoing development of neural circuits that underlie empathy. While affective responsiveness is present in infancy and begins as an involuntary process relying on emotional mimicry and somato-sensorimotor resonance between the observer and target (Decety & Michalska, 2010), the developing cognitive component of empathy gradually modulates this experience of vicarious emotion and changes individuals' experience of affective empathy as they progress through adolescence. Early to late adolescence is a particularly critical period to observe these shifts in experiences of vicarious emotion, as the cognitive component of empathy largely involves the prefrontal cortex, which follows a protracted developmental course and does not reach full maturity until late adolescence (Bunge et al., 2002; Zelazo et al., 2008). Thus, age-related changes in affective empathy, given maturation of the prefrontal cortex, set up adolescence as a particularly important period to observe this evolution of the empathic experience.

As prefrontal regions mature, there appears to be a shift in the empathic response one can have to an emotional event, a switch from relying on limbic-related structures of affect sharing to more frontal regions involved in emotion understanding (Killgore & Yurgelun-Todd, 2007). This shift involves moving from a visceral emotional response, which is important for understanding the affective significance of a stimuli, to a more evaluative one (Decety, 2010).

Additionally, in an investigation examining age-dependent changes in the neural substrates of empathy in a sample of typically developing control (TDC) adolescents (compared to adolescents with autism spectrum disorder), TDC adolescents' self-reported empathy was negatively correlated with AI activity while empathizing with an emotional facial display (Schulte-Rüther et al., 2014). This is interesting, as the insular cortex has been frequently tied to processes like shared affect, particularly for experiences like pain and dispositional differences in empathy (Carr et al., 2003; Greimel et al., 2010; Singer et al., 2004). However, Schulte-Rüther and colleagues suggest that monitoring one's own emotional states while empathizing becomes more automatic with increasing age, and thus less necessary for producing an empathic response. As adolescents continue to navigate their social worlds and come across increasing socioemotional interactions with others, they may begin to rely less on sharing the emotional states of another and can instead begin relying on higher-order processing to understand the target's emotions.

However, it is important to note that many of these findings examining affective empathy arise from context-independent events, like viewing images of individuals in pain or emotional facial displays. When examining empathy for a more abstract situation, such as witnessing a social exclusion that requires mental work in order to understand the target's mind state and experience, early/middle adolescents (13-year-olds) are already exhibiting greater activity in cognitive regions (i.e. dmPFC, mPFC) when viewing the social exclusion (vs. inclusion) of a target, with no significant activity in social pain-related neural regions like the dACC and AI (Masten et al., 2011).

Adolescence is a crucial period in which prefrontal regions involved in perspective taking are slowly coming online, reaching maturation only in late adolescence (Decety, 2011; Decety & Meyer, 2008; Dumontheil et al., 2010). Thus, the patterns of neural activation underlying empathy show age-related changes as adolescents increasingly learn to evaluate a situation and take another's perspective, leading to a potentially less visceral emotional response when empathizing.

The development of cognitive empathy throughout early to late adolescence has also been investigated through behavioral measures, in which studies concluded that both emotion recognition and perspective taking improve with age. For example, in a study by Schwenck et al. (2014), children and adolescents ages 7 to 17 years old were shown film clips of different social interaction scenes, in which they were asked to choose the emotions the protagonist of the story had felt during the scene they viewed. To measure perspective taking, participants were asked to take the perspective of the protagonist and explain why he felt the way he did. Results revealed that age had a strong influence on cognitive empathy, such that both emotion recognition and affective perspective taking abilities increased with age. Overall, previous studies examining cognitive empathy using self-report, behavioral, and neural measures have suggested that this component of empathy increases and improves throughout adolescence.

While the differing developmental trajectories of affective and cognitive empathy align with the neurodevelopment of the distinct neural networks that support each component, the development of prosocial concern has more frequently been measured using self-report or behavioral studies. Given that prosocial behaviors such as helping, comforting, sharing, and cooperating have been observed in infants as young as 12 months of age (Tousignant et al., 2017; Vaish et al., 2009), it seems as though prosocial concern is already online at an early age. In an attempt to more clearly identify the potential predictors of prosocial behavior and how they might vary during adolescence, one study examined the longitudinal links between perspective taking and empathic concern with prosocial behavior (Van der Graaff et al., 2018). In this 6-wave longitudinal study, researchers defined empathic concern as feelings of sorrow for someone else, and found empathic concern to be longitudinally related to subsequent prosocial behavior, with perspective taking being indirectly related to subsequent prosocial behavior through its effect on empathic concern. However, other studies suggest a different pattern, as Peplak and Malti (2021) found 15-year-olds to report less concern toward the suffering of a victim than 11-year-olds. In a longitudinal study examining both perspective taking and empathic concern across a 6-year period, research showed that while perspective taking generally increased across adolescence, empathic concern was either stable (for girls) or followed a U-shaped curve (for boys) (Van der Graaff et al., 2014). Much work examining the development of empathic concern has come from behavioral studies, and has not examined the development or involvement of the neural correlates that underly prosocial concern, particularly in the involvement of mammalian and human caregiving-related regions like the septal area and mOFC.

Gender Differences in Empathy

When developing an understanding of empathy and its development across the lifespan, it is important to consider frequently noted gender differences across various investigations on empathy as well. Gender differences in empathy have been observed as early as infancy, as female infants have been shown to be more likely to cry in response to other babies crying (contagious crying; Hoffman, 1977) and are more skilled at imitating finger movements compared to male infants (Nagy et al., 2007). While more studies investigating gender differences in infancy are needed to establish that these findings are consistent and reflect differences in empathy rather than precursors for other social behaviors, the tendency for females to show higher levels of empathy and respond to other's distress with greater concern is reported at 2 years of age as well (Hoffman, 1977; Zahn-Waxler et al., 1992). While these differences, such that females show higher levels of empathy than males, continue to be reported from infancy to pre-adolescence (see Christov-Moore et al., 2014 for full review), the differences only widen come adolescence (Balk, 1995; Lam et al., 2012), such that adolescent girls are reporting significantly higher levels of empathy across self-report measures (Davis & Franzoi, 1991) and are more likely to help a victim of bullying compared to adolescent boys (Jolliffe & Farrington, 2006).

II. Current Investigation

There are multiple factors at play when someone sees another person suffering, and as a result, encountering that suffering can lead to various responses. Empathy is at the core of these emotional responses, but given empathy’s complexity, it is crucial to deconstruct and understand the different means by which one can have an empathic experience. At the heart of empathy’s multidimensionality is the bottom-up and top-down information processing involved in an empathic experience, which have also been considered the affective and cognitive components of empathy. While research within the fields of social psychology, developmental psychology, and neuroscience have varied in their definition and measurement of these two components, social affective neuroscience has allowed for brain-behavior links to be made, thus clarifying lingering questions and debates that relied solely on neuroscience, behavior, or self-report data alone. Additionally, while there is general agreement amongst scholars that empathy includes both affective and cognitive components, some scholars have included a third component, prosocial concern, in the understanding of empathy. Together, these three components have been shown to rely on differing neural networks which develop at different rates across the lifespan, a difference that is particularly exaggerated in adolescence.

Given these building blocks of empathy, it is crucial to understand how they are involved in empathic experience throughout adolescence, and how they predict subsequent prosocial behavior. An interesting way to isolate these components is by studying empathy in adolescence. Adolescence is a period marked by great socioemotional and cognitive changes; however, these systems have different maturational trajectories. While both socioemotional and cognitive control systems develop across this period, the cognitive control system has been shown to undergo a more protracted course of development. Given this mismatch, there is evidence to suggest that adolescents may be approaching an empathic experience differently than an individual with a fully matured cognitive control system. Thus, adolescence presents a unique and important window to examine changes in affective and cognitive empathy in real-time, looking across age to understand how an empathic experience may evolve as a result. While previous research suggests that adolescents increasingly adopt greater perspective taking skills to form a mature empathic response, as more automatic experiences of affect sharing decrease with age, there remain gaps in the literature regarding how the interaction of these components may differentially motivate prosocial sentiments and behavior as a result. Importantly, the involvement of each component of empathy in producing an empathic response may vary depending on the situation at hand. For adolescents, observing and feeling empathy for a negative social situation ('social pain') involving peer rejection is likely a more common and salient experience. Given the increased frequency of negative social experiences in addition to adolescents' greater sensitivity to peer acceptance, experiencing empathy for 'social pain' is particularly interesting and important to investigate during this period. Additionally, understanding how the experience of viewing an exclusion relates to subsequent helping of the victim is crucial to uncover, as it allows for a developmental investigation of the neural correlates of prosocial concern.

Aims

The primary aim of this dissertation is to understand what features of empathy for another's social pain can work to predict subsequent prosocial behavior, and how this may vary by age and gender, considering the socioemotional and neurodevelopmental changes that occur throughout adolescence.

In line with this overarching aim, self-reported trait measures of empathy and prosocial tendencies were investigated, in terms of (1) how they differ by age and gender, (2) how they can predict task-based state empathy and prosocial behavior, and (3) how they relate to neural activity while viewing the exclusion of a same-aged peer.

III. Method

Participants

Data for this study comes from the second wave of the UCLA Brain Power Study, a three-wave longitudinal neuroimaging study examining the neural and behavioral development of prosocial behavior. Youth were recruited during the first wave of data collection via flyers, advertisements, and through class presentations to schools within Los Angeles school districts, and from the Clinical and Translational Science Institute (CTSI) database of families in the UCLA and affiliated medical systems. All participants were recruited from the first wave of participants, who returned for the second wave of data collection after 2 years.

The full sample included 142 participants who were exactly half female (50%, n = 71), with a self-reported ethnic composition of 35.2% European American, 24.6% Multi-ethnic, 13.4% Hispanic/Latinx, 8.5% Asian American, 9.2% African American, 6.3% Other, and 2.8% Native American. This included participants aged 11 (n = 21), 12 (n = 27), 13 (n = 27), 14 (n = 17), 15 (n = 27), 16 (n = 18), and 17 (n = 5). Participants were fully compensated with funding from the longitudinal parent grant (up to $84). Participants were excluded from the study if they presented any of the standard fMRI contraindications, including left-handedness, metal in the body, or a previous diagnosis of a psychiatric, neurological, or developmental condition determined during a pre-session phone screening prior to their visit. Sample size ranges depending on analysis, as 13 participants only completed pre-session questionnaires (self-reported empathy and prosocial tendencies measures) and did not view the Cyberball game, 19 participants were excluded from self-reported trait empathy analyses either because they (1) did not complete the IRI questionnaire, or (2) did not pass the attention check for the measure (Interpersonal Reactivity Index). Several participants (n = 4) did not notice the exclusion during the Cyberball game and were thus excluded from any task-related analyses. Participants were also excluded from the imaging analyses as well, due to either excessive motion (n = 3) or because they were consistent outliers across the ROI analyses (i.e. outside the Interquartile Range, n = 2). Overall, 119 participants had usable self-report pre-session data while 123 participants had neuroimaging data.

Procedure Overview

Participants were screened for eligibility ahead of their session and completed baseline questionnaires via Qualtrics prior to coming into the lab. All sessions were conducted at the UCLA Staglin Center for Cognitive Neuroscience (CCN). At their session (prior to entering the fMRI scanner) participants were told that they would be watching three previous participants of the study play an online ball-tossing game during their scan, and were given the first names of the ‘previous participants’ that will be playing (one boy, one girl, and the excluded player, whose gender was matched with the participant; Masten et al., 2011). Participants were instructed to think about what the players might be thinking or feeling while they are playing, how they are treating each other, and what strategies they might be using to decide who to throw the ball to. Participants then viewed two rounds of this pre-recorded game while in the scanner, in which one player is eventually excluded from the game in the second round (“Cyberball”; Williams et al., 2000; see Figure 1). After the scan, participants were given the opportunity to write and send a message to each of the players in the ball-tossing game and were told that their messages would be shared anonymously with each of the players after the session. These messages were later coded as a measure of prosocial behavior by independent raters.

Participants then completed a manipulation check to be sure they noticed the exclusion of one of the players in the second round and answered several questions regarding how they felt while watching the game, as a measure of state empathy in response to viewing the exclusion. At the conclusion of the study, participants asked several questions regarding any suspicions they might have had in response to the Cyberball game and were subsequently fully debriefed regarding the deception and overall aim of the study.

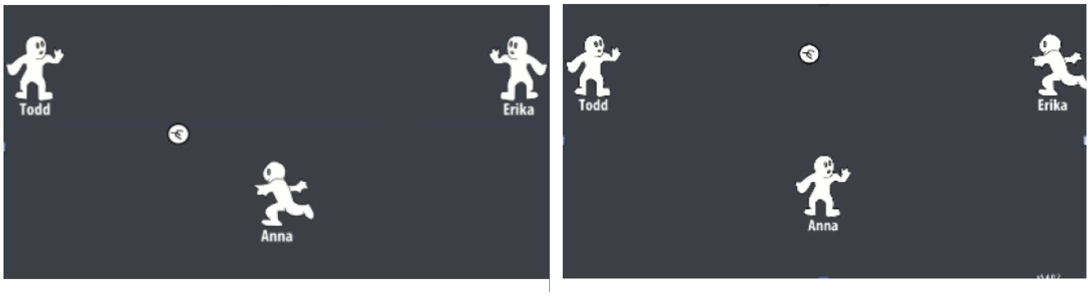


Figure 1 Example of Cyberball Game

Left: an example of round 1 of the game, where all players are included in the game. Right: an example of round 2 of the game, where Anna (or Adam) is excluded from the game after 10 throws of inclusion. The excluded player's name is gender-matched with the participant.

Measures

Trait Empathy and Prosocial Tendencies

Prior to coming in for their study session, participants completed measures of both trait empathy and prosocial tendencies. Trait empathy was measured using two subscales of the Interpersonal Reactivity Index (IRI; Davis, 1980) – the perspective taking and empathic concern subscales (14 items total). The perspective taking subscale included 7 items aimed at assessing the tendency to spontaneously adopt other people's points of view (e.g. "I sometimes try to understand my friends better by imagining how things look from their point of view"; chronbach's α = .788). The empathic concern subscale is a 7-item subscale aimed at measuring the tendency to feel sympathy or concern for those in need (e.g. "I often have tender, concerned feelings for people less fortunate than me"; chronbach's α = .755).

Trait prosocial tendencies was measured using the short 5-item prosocial subscale of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997). The 5 items of this subscale included: "I try to be nice to people. I care about their feelings", "I usually share with others (food, games, pens, etc.)", "I am helpful if someone is hurt, upset, or feeling ill", "I am kind to younger children", and "I often volunteer to help others (parents, teachers, children)", chronbach's α = .828, which were rated on a 1 = not true to 5 = certainly true scale.

Pubertal Development

Participants also completed the Pubertal Development Scale (PDS; Petersen et al., 1988), a scale in which participants self-report on the visible development of their secondary sexual characteristics (e.g. growth in height, body hair, skin changes) on a scale of 1 (no development) to 4 (almost complete development). Averages were calculated across 4 items for boys (chronbach's α = .865), and 5 items for girls (chronbach's α = .897), with an additional item for girls regarding whether they have started their period (no receiving a score of 1, yes receiving a score of 4).

Prosocial Ratings of Cyberball Messages

Four independent raters who had no prior involvement with the study or interaction with the study participants read and coded the messages participants wrote to both the victim and excluders of the Cyberball game. For the messages participants wrote to the victim of the exclusion (Anna or Adam), raters responded to three questions:

Does it seem like they are trying to comfort this person?

How supportive are they toward this person?

How much do they seem like they are trying to help this person?

These questions came from previous work using the same paradigm to measure prosocial behavior, and similar to those studies, raters were asked based on their impression of the message to answer each question on a 7-point scale, where 1 = not at all and 7 = very much (Masten et al., 2010; Masten et al., 2011). The raters were highly aligned on their scoring across each question (*ICCs > .86*) the ratings for each question were averaged across the raters.

Participants were also given the opportunity to write messages to each of the excluders (Todd and Erika). These messages were also coded for degree of prosocial behaviors, based on the extent to which the participant was defending the victim or reprimanding the excluders in the message. Raters answered one question for each message to both Todd and Erika:

Does it seem like they are trying to defend the victim?

Raters answered this question on a 1-7 scale, with 1 = not at all and 7 = very much. There was high reliability for both messages to Todd and Erika across the raters (*ICC = .97*) so ratings were averaged across raters and then averaged between Todd and Erika to get a single score for defending the victim. Given that defense is a form of prosocial behavior defined by the intent to help victimized individuals (Geraci & Franchin, 2021; Eisenberg & Spinrad, 2014; Lambe & Craig, 2020) and contributes to social well-being (Dirks et al., 2018), the current investigation included this measure of defense in the overall measure of prosocial behavior. Given high reliability between the 3 measures of support for the victim and 1 measure of defense of the victim to the excluders (chronbach's α = .926), the ratings were averaged to compute a single score for prosocial behavior in response to the Cyberball game.

State Empathy

After writing messages to the players of the game, participants were asked on a Likert scale ranging from 1 (not at all) to 5 (very much so) to rate the extent which they felt the following feelings while they were watching the player who was being treated unfairly: "I felt bad for him/her, I wanted to help him/her, I did not care about him/her, I wanted to give him/her the ball, it hurt to watch him/her play, I wish I could tell the other kids to throw him/her the ball, I wanted to talk to him/her afterwards, I felt sad for him/her, I wanted to tell him/her it was ok, I felt sorry for him/her". Responses to these 10 items were averaged to create a self-report, state measure of empathy regarding how the participant felt while watching the social exclusion (chronbach's α = .927).

Manipulation Check

Participants were subsequently asked a series of several "Yes/No" questions regarding whether they noticed all players participating in the game, if one player acted like the leader or had control, if one player was being treated unfairly by the other players, whether all players seemed like they wanted to play the game, whether two players 'ganged up' on a third player, if every player treated the other players equally, if one player seemed left out of the game, and if all players got the ball the same amount (based off prior work; Masten et al., 2010; Masten et al., 2011). If participants indicated that they did not notice that one player was left out of the game by the others, they were excluded from any analysis related to Cyberball (n = 4).

fMRI Data Acquisition

Imaging data are acquired on a Siemens 3 Tesla Prisma Fit MRI scanner at UCLA's Staglin International Mental Health Research Organization Center for Cognitive Neuroscience. Firstly, A T2-weighted high-resolution magnetization-prepared rapid-acquisition gradient echo (MPRAGE) anatomical scan is acquired (TR: 2.3 s; TE: 2.1 s; matrix: 192x192; slice thickness: 1 mm; 160 slices). All subsequent functional runs of the study consist of T2*-weighted echoplanar images (TR: 2 s; TE: 30 ms; flip angle: 90°; matrix: 64x64; voxel size: 3x3x4 mm; slice thickness: 4 mm; 34 slices). The Cyberball game consists of two functional runs and is projected onto a screen behind the scanner which the participant can view through a mirror attached to the head coil.

IV. fMRI Data Preprocessing and Analysis

fMRI data preprocessing

Neural data was preprocessed and analyzed using Statistical Parametric Mapping 12 (SPM12; Welcome Department of Cognitive Neurology, Institute of Neurology, London, England). Functional runs were realigned to the mean functional image and resliced to correct for head motion for each participant. Translational movement parameters could not exceed 3 voxels (3.125 mm inplane, 4mm throughplane) in any direction for any subject. If they did, subjects were excluded from the analyses (3 participants). In cases where translational motion of more than 2 mm from one image to the next is detected, individual nuisance regressors were added to remove such images from the analyses. MPRAGE was normalized to Montreal Neurological Institute (MNI) space using diffeomorphic anatomical registration through exponentiated lie (DARTEL) algorithms. Functional images underwent spatial smoothing using a 5 mm full-width-half-maximum Gaussian kernel.

Modeling of Contrasts

Cyberball was modeled as a block design, where the inclusion period consisted of two blocks (the first round of the game which only comprised of inclusion, and the period of inclusion in the second round preceding the exclusion of Anna or Adam). The period of exclusion (in round 2) in which Todd and Erika passed the ball to each other, leaving Anna or Adam out, comprised the exclusion block. For analysis, we solely focused on round 2 of the Cyberball game, to create a contrast of exclusion versus inclusion within the same round (functional run) of the game. The initial period of inclusion in the second round consisted of 10 throws of inclusion (20 seconds) and the exclusion period consisted of 50 throws between Todd and Erika (92 seconds). To avoid boredom effects and more closely match the inclusion period in length of time, the main linear contrast of interest compared the first half of the exclusion period (46 seconds) compared to the initial period of inclusion in round 2 (20 seconds). This linear contrast was calculated for each participant and used in the Region of Interest (ROI) analyses.

Regions of Interest (ROIs)

Given prior research on the neural correlates of empathy, neuroimaging analyses focused on a priori regions of interest (ROIs) associated with the affective, cognitive, and prosocial concern components of empathy. ROIs associated with the affective component of empathy included the dorsal anterior cingulate cortex (dACC) and bilateral anterior insula (AI). The dACC ROI was created by combining Brodmann areas 32 and 24, and uses a rostral boundary of y = +36, and a caudal boundary of y = 0 (Dedovic et al., 2016; Slavich et al. 2010; Way et al. 2009). The AI ROI was defined by cutting the anatomical AAL Insula ROI at its midpoint of y=0, approximately separating dysgranular and granular insula (Slavich et al., 2010). ROIs associated with the cognitive component of empathy included the posterior superior temporal sulcus (pSTS), dorsomedial prefrontal cortex (dmPFC), and temporoparietal junction (TPJ). The pSTS ROI was created by extending the Desikan-Killiany Atlas (Desikan et al., 2006) defined bank superior temporal sulcus to the border of the TPJ (Mills et al., 2014). The dmPFC ROI was defined using Neurosynth by searching and downloading the dmPFC region in the automated meta-analysis tool and masking this with the medial frontal gyrus form the WFU PickAtlas, based on prior work (Maldjian et al., 2003, Yarkoni et al., 2011). The TPJ ROI was created by combining the right TPJ, comprised of 2812 voxels all $z > 6$ mm, centered at [54 − 52 23] and the left TPJ, comprised of 2444 voxels all $z > 6$ mm centered at [− 52 − 58 25], following past work (Dufour et al., 2013). All ROIs comprising the cognitive component of empathy came from previous work coming from the first wave of data collection from this study (see Karan, Lazar, et al., 2022). Finally, ROIs for prosocial concern included the septal area (SA) and medial orbitofrontal cortex (mOFC). The SA ROI was defined according to microscopic sections (Nieuwenhuys et al., 1978) between $y = 0$ and $y = 14$ that show the location of the septal nuclei at coronal sections through the anterior commissure and anterior to the optic chiasma. Given the small nature of the septal nuclei, the ROI used also encompasses the larger surrounding area (Zahn et al., 2009). The mOFC ROI was defined by first creating an anatomical bilateral OFC ROI using the Automated Anatomical Labeling atlas (AAL; Tzourio-Mazoyer et al., 2002) and slicing it medially from $x = -10$ to $x = 10$ to specifically examine the medial OFC.

Mean parameter estimates were extracted from the ROIs for each participant and entered into standard statistical software for further analysis. To avoid issues of multiple comparisons, ROIs comprising each component of empathy (affective, cognitive, prosocial concern) were averaged together to form Affective Pain, Mentalizing, and Prosocial Concern networks. All analyses tested the neural activity at the network level, rather than ROI-by-ROI (see Figure 2).

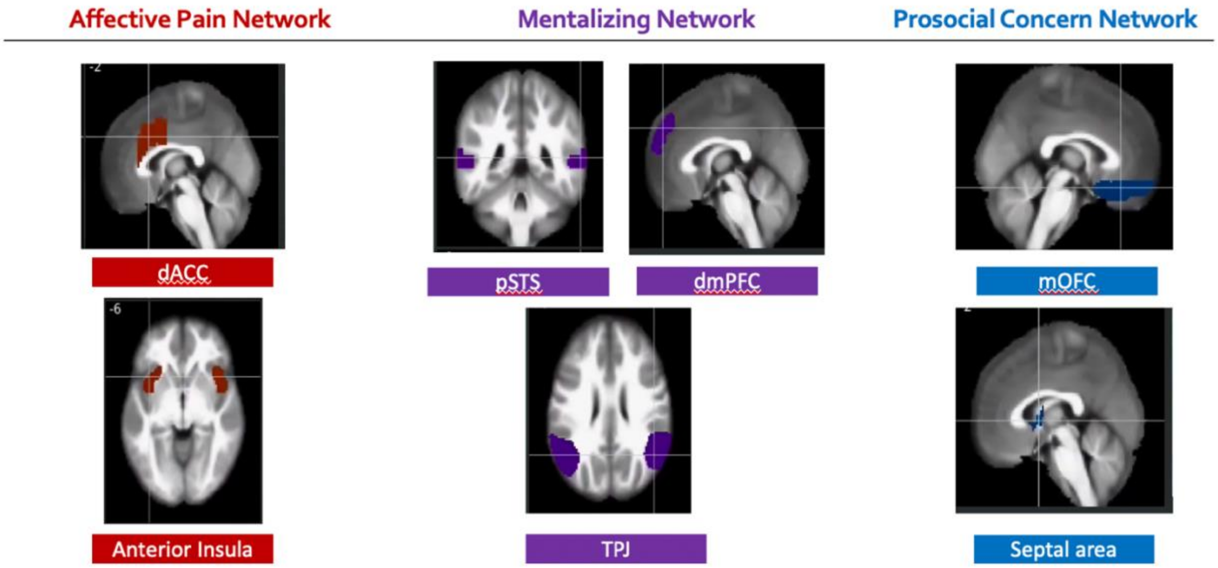


Figure 2 Regions of Interest

The Affective Pain network (left) comprised of the dorsal anterior cingulate cortex (dACC) and anterior insula (AI). The Mentalizing network (middle) comprised of the posterior superior temporal sulcus (pSTS), temporoparietal junction (TPJ), and dorsomedial prefrontal cortex (dmPFC). The Prosocial Concern network (right) comprised of the medial orbitofrontal cortex (mOFC) and septal area (SA).

V. Analysis Plan

Neural Activity during Exclusion vs Inclusion

Neuroimaging analyses solely focused on ROIs, which were extracted and combined into Affective Pain, Mentalizing, and Prosocial Concern networks. One-sample t-tests were conducted to test whether there was significant activation (activation above 0) in Affective Pain, Mentalizing, and Prosocial Concern networks during exclusion vs inclusion across the entire sample. Instead of running analyses on an ROI-by-ROI basis, networks were tested to avoid issues of multiple comparison. Thus, no thresholding was done at the network level. However, multiple hypothesis testing was controlled for via FDR correction, and was applied to sets of analyses (Benjamini & Hochberg, 1995; see below).

Age and Gender Differences in Empathy and Prosocial Behavior

Firstly, to understand how trait perspective taking, empathic concern, and prosocial tendencies were related to each other, Pearson correlations were computed.

Given consistent evidence from previous work reporting significant changes in empathy throughout adolescence (Allemand et al., 2015; Crone & Dahl, 2021), along with gender differences that continue to widen during this period as well (Michalska et al., 2013; van der Graaff et al., 2014), it was important for the current investigation to explore differences across age, gender, and the interaction of age and gender in predicting all measures of empathy and prosocial behavior. To do so, age, gender, and an age by gender interaction term were tested in multiple linear regression models predicting self-reported trait measures (perspective taking, empathic concern, prosocial tendencies), along with self-report and behavioral measures in response to Cyberball (state empathy and prosocial behavior) and neural activity during exclusion vs inclusion (Affective Pain, Mentalizing, Prosocial Concern networks). Each group of analyses (trait measures, state empathy and prosocial behavior measures, network measures) were corrected using a false discovery rate (FDR) threshold of $p < .05$ to control for multiple comparisons. For results with initial p-values < .05, adjusted p-values after FDR correction are presented.

Trait Predictors of State Empathy and Prosocial Behavior

To then investigate how these trait measures of empathy and prosocial tendencies go on to predict state empathy and prosocial behavior from the Cyberball game, a multiple regression model was used to test effects of perspective taking, empathic concern, and prosocial tendencies (with age and gender included in the model) predicting prosocial behavior and state empathy. Subsequent exploratory models tested an interaction term of each trait measure by age and trait measure by gender. All trait measures were kept in the model and controlled for while testing each different interaction, predicting state empathy and Cyberball prosocial behavior. While three-way interactions (age by gender by trait measure) were examined, none were significant, and thus the analyses focused on two-way interactions with just age and just gender. Groups of analyses (models testing interactions by age, and models testing interactions by gender) were each corrected using a false discovery rate (FDR) threshold of $p < .05$ to control for multiple comparisons. For results with initial p-values of < .05, adjusted p-values after FDR correction are presented.

Trait Predictors of Neural Activity

Mirroring previous analyses, age, gender, and trait measures were included in a multiple regression model predicting network activity (Affective Pain, Mentalizing, Prosocial Concern). Subsequent exploratory models tested an interaction term of each trait measure by age and trait measure by gender. All trait measures were kept in the model and controlled for while testing each different interaction, predicting network activity during exclusion. While three-way interactions (age by gender by trait measure) were examined, none were significant, and thus the analyses focused on interactions with just age and just gender. Groups of analyses (models testing interactions with age, models testing interactions with gender) were each corrected using a false discovery rate (FDR) threshold of $p < .05$ to control for multiple comparisons. For results with initial p-values of < .05, adjusted p-values after FDR correction are presented.

Neural Predictors of State Empathy and Prosocial Behavior

Finally, to answer the primary research question of which neural correlates of empathy predict subsequent prosocial behavior, age, gender, Affective Pain, Mentalizing, and Prosocial Concern networks were included in a multiple regression model predicting state empathy and prosocial behavior. In line with previous analyses, subsequent exploratory models tested an interaction term of network by age and network by gender. All networks were kept in the model and controlled for while testing each different interaction, predicting state empathy and prosocial behavior. While three-way interactions (age by gender by network) were examined, none were significant, and thus the analyses focused on interactions with just age and just gender. Groups of analyses (models testing interactions with age, models testing interactions with gender) were each corrected using a false discovery rate (FDR) threshold of $p < .05$ to control for multiple comparisons. For results with initial p-values of < .05, adjusted p-values after FDR correction are presented.

VI. Results

Descriptive information

Participants displayed a range in trait empathic concern (range: 1.43 – 4; M = 2.75, SD = 0.56), perspective taking (range: 0.86 – 4; M = 3.14, SD = 0.63), and prosocial tendency scores (range: 1.2 – 5; M = 3.8, SD = 0.75). Self-report trait perspective taking and empathic concern were correlated ($r(122) = .612$, $p < .001$) and prosocial tendencies was correlated with both perspective taking ($r(118) = .615$, $p < .001$) and empathic concern ($r(118) = .546$, $p < .001$). The average score on pubertal development (range 1 – 4) was 2.8, with girls (M = 3.12) significantly farther along in puberty than boys (M = 2.5), $t(116) = -4.63$, $p < .001$. Participants who viewed the Cyberball game and indicated that they were aware of the exclusion reported a range of state empathy levels (range: 1 – 5; M = 3.43, SD = 0.9).

Prosocial Ratings of Messages to Cyberball Players

Of the 121 participants that viewed the Cyberball game in the scanner and indicated that they noticed the exclusion, 24 participants (19.8%), chose not to write anything to any of the players, 5 participants (4.1%) only wrote a message to the victim, and 13 participants (10.7%) only wrote messages to the excluders. To utilize every message that participants wrote to the players as a measure of prosocial behavior, average scores were calculated based on the data that was available. Thus, for participants who only wrote a message to the victim, the 3 items that raters scored related to supporting the victim were used as their final prosocial score. Likewise, for participants who only wrote messages to the excluders, ratings of defending the victim were used as their final score on prosocial behavior. The participants displayed a wide range of both comforting the victim and defending the victim to the excluders. An example of a high overall prosocial score is:

> Message to victim: *“Anna, you played well in the First Round. I am sorry you didn’t get to play the Second Round because of Todd and Erika’s selfishness. Hopefully next time they will include you. If they don’t, don’t play ball with them anymore.”*
>
> Message to excluders: *“Erika, you played well in the First Round. In the Second Round, you were good at playing but you didn’t ever pass to Anna. She was open the whole round and yet the only person you passed the ball to was Todd. Next time you should include her.”*

While an example of a low overall prosocial score is:

> Message to victim: *“Hello Adam, the second round you and the others played was pretty amusing, especially because the others would not pass to you.”*

> Message to excluders: *"Hello Erika, It was pretty fun watching you guys play in the second round because of the fact you would only pass to Todd."*

Degree of Cyberball prosocial behavior varied (range: 1 – 7; M = 3.43, SD = 1.89).

Neural Activity during Exclusion vs Inclusion

Viewing the exclusion of a same-aged peer during the Cyberball game was associated with significant activation in both the Affective Pain (t(120) = 2.55, p = .012) and Mentalizing (t(120) = 3.13, p = .002), but not Prosocial Concern, networks (see Figure 3).

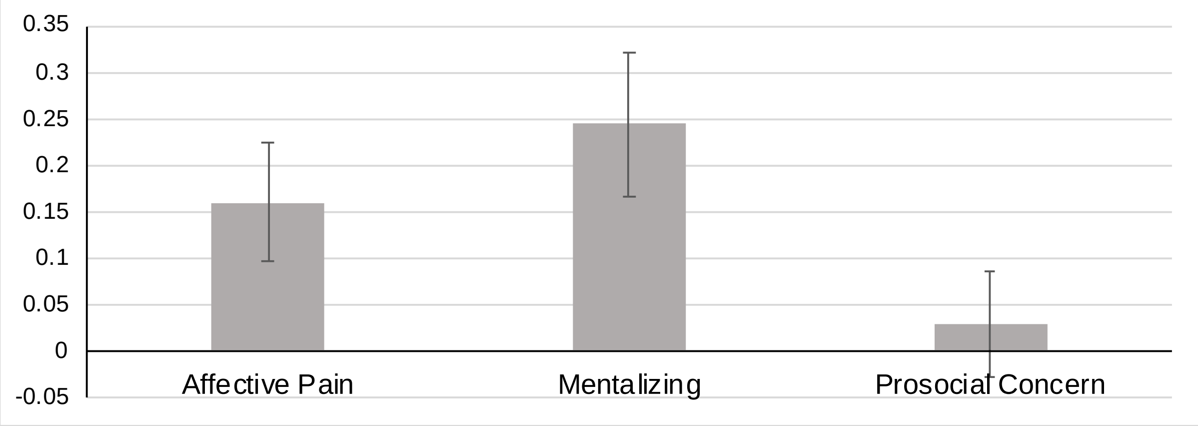


Figure 3 Significant neural activation during exclusion vs inclusion

The Affective Pain (M = .244, SE = .078; left) and Mentalizing (M = .16, SE = .063; middle) networks showed significant activation during exclusion vs inclusion (significantly above 0), while the Prosocial Concern network (M = .029, SE = .056; right) did not.

Age and Gender Differences in Empathy and Prosocial Behavior

Trait Measures of Empathy and Prosocial Tendencies

There were no age, gender, or age by gender interactions for empathic concern (Table 1; Figure 4a & b) or perspective taking (Table 1; Figure 4c & d).

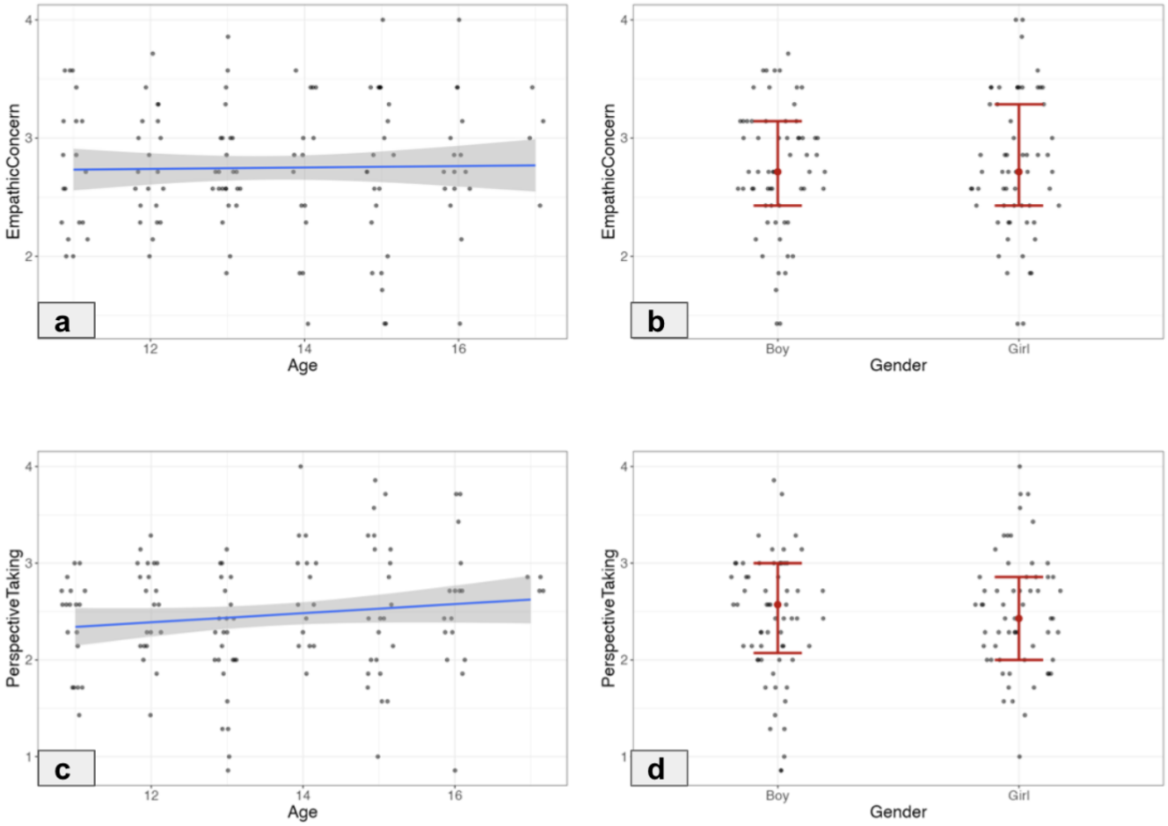


Figure 4 Age and gender distributions for empathy and prosocial tendencies

For trait empathic concern, no age (a) or gender (b) effects were found. Similarly for trait perspective taking, no age (c) or gender (d) effects were observed.

Results showed a significant age by gender interaction for prosocial tendencies (Table 1; β = .348, p = .048; p = .144 after FDR correction), such that by the age of 15 years old (and above), girls are reporting significantly greater levels of prosocial tendencies compared to boys (β = .523, p = .023; Figure 4). However, the adjusted p-value after FDR correction is not statistically significant.

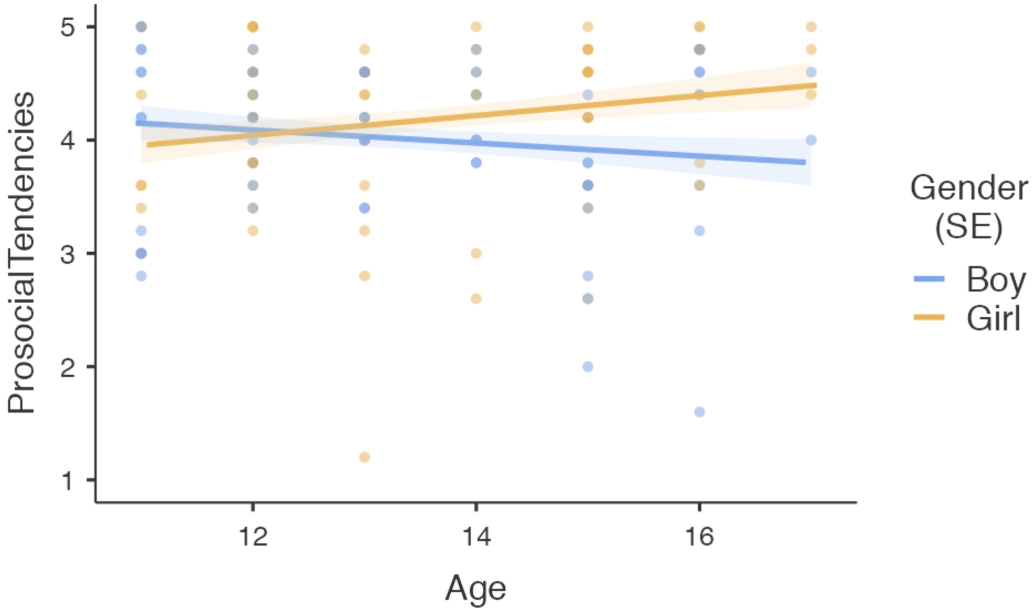


Figure 5 Gender by age interaction in prosocial tendencies

A significant gender by age interaction, such that for girls reported significantly greater prosocial tendencies by age 15 (β = .523, p = .023*). This result did not pass multiple comparison correction.*

Table 1 Age and Gender Differences in Empathy and Prosocial Concern

	Perspective Taking		Empathic Concern		Prosocial Tendencies	
	β	SE	β	SE	β	SE
Age	0.1308	0.0326	0.0187	0.0292	0.0358	0.0364
Gender	0.0455	0.1140	0.0422	0.1021	0.2306	0.1292
Age ∗ Gender	0.1589	0.0651	0.2780	0.0583	**0.3477***	**0.0728**

Note. ∗p < .05, ∗∗ p < .01, ∗∗∗p< .001

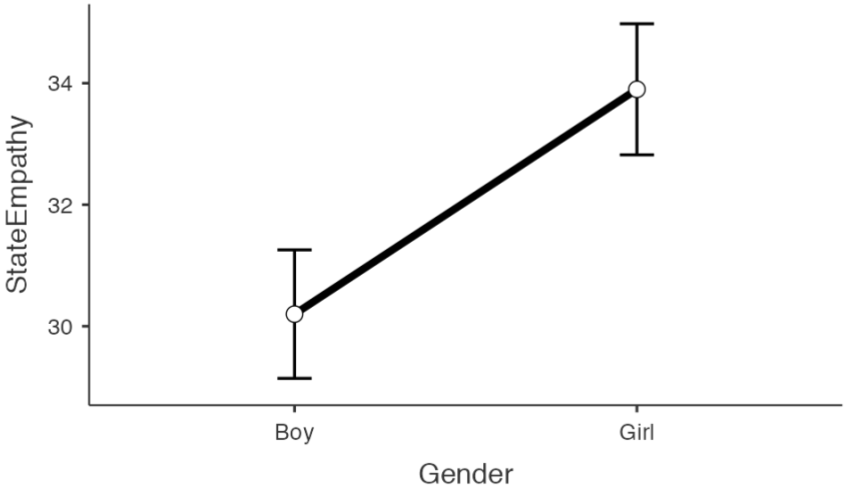
State Empathy and Prosocial Behavior

Analyses revealed a main effect of gender on both state empathy (β = .49, p = .006; p = .018 after FDR correction) and prosocial behavior (β = .39, p = .045; p = .067 after FDR correction), independent of the presence of the interaction with age (interaction terms *p > .12,* Table 2). This suggests that gender has a significant impact on both state empathy and prosocial behavior, regardless of age. Girls reported higher levels of state empathy (M =33.6, SE = .99) compared to boys (M = 29.6, SE = 1; Figure 5a), and wrote more prosocial messages to the players of the Cyberball game (M = 3.79, SE = .265) compared to boys (M = 3.03, SE = .263; Figure 5b). However, the gender difference in prosocial behavior did not remain significant after FDR correction.

Table 2 Age & Gender Diffs in State Empathy and Prosocial Behavior

	State Empathy		Prosocial Behavior	
	β	SE	β	SE
Age	0.0368	0.398	0.0964	0.105
Gender	**0.4904****	**1.408**	**0.3995***	**0.373**
Age ✻ Gender	0.2722	0.797	0.0894	0.210

*Note. *p < .05, ** p < .01, ***p< .001*



a)

b)

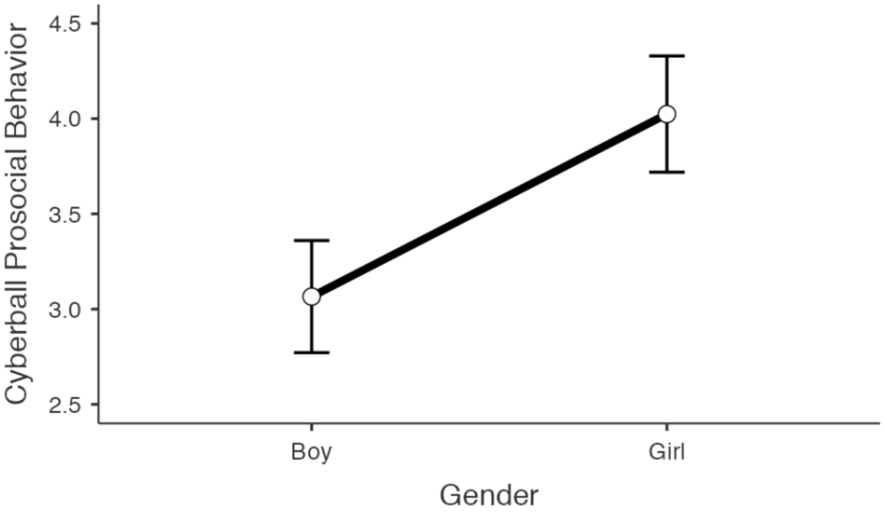


Figure 6 Gender differences in state empathy and prosocial behavior

(a) Significant gender difference in state empathy, such that girls report significantly greater levels of state empathy after viewing the exclusion compared to boys (b) Significant gender difference in degree of prosocial behavior in the messages to players of the Cyberball game, such that girls wrote significantly more prosocial messages than boys. This result did not pass FDR correction.

Affective Pain, Mentalizing, and Prosocial Concern Networks

Analyses revealed no significant effects of age, gender, or an age by gender interaction predicting Affective Pain or Prosocial Concern network activity (Table 3). However, results show a significant main effect of gender on Mentalizing network activity (β = .39, p = .029; p = .05 after FDR correction), independent of the presence of the interaction with age (interaction term p = .763, Table 3). Girls (M = .42, SE = .11) showed significantly higher activation in the

Mentalizing network while viewing the exclusion (vs inclusion) compared to boys (M = .08, SE = .11; Figure 6).

Table 3 Age and Gender Differences in Networks

	Affective Pain		Mentalizing		Prosocial Concern	
	β	SE	β	SE	β	SE
Age	-0.0458	0.0364	-0.0503	0.0445	0.0461	0.0328
Gender	0.1354	0.1267	**0.3991***	**0.1550**	-0.0370	0.1144
Age ✻ Gender	-0.1427	0.0728	-0.0552	0.0891	-0.0504	0.0655

*Note. *p < .05, ** p < .01, ***p< .001*

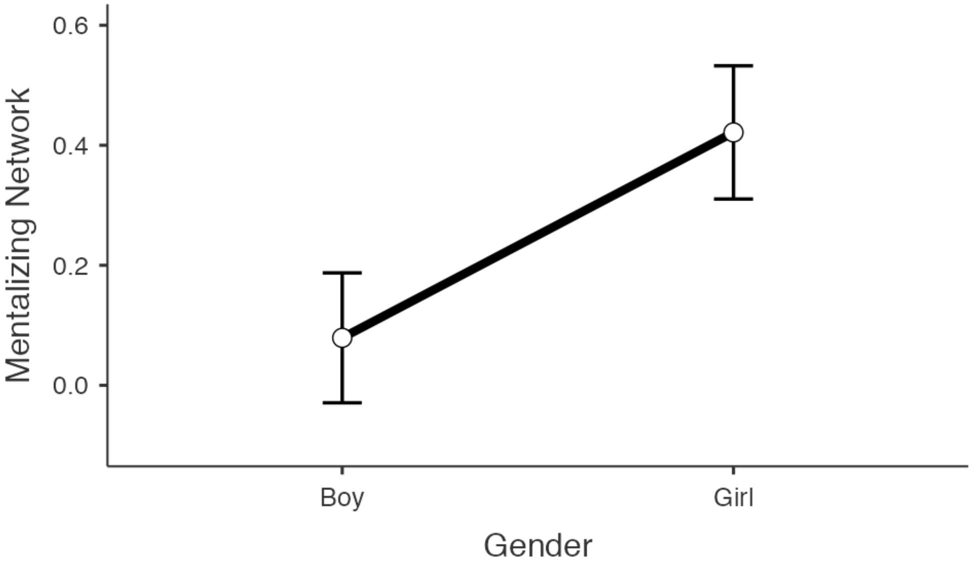


Figure 7 Gender differences in Mentalizing

Significant *gender differences in Mentalizing network activity while watching the exclusion vs inclusion in Cyberball, such that girls show significantly greater activation in Mentalizing than boys.*

Trait Predictors of State Empathy and Prosocial Behavior

The multiple linear regression revealed a significant main effect of empathic concern on state empathy, such that those higher in self-reported empathic concern also reported higher levels of state empathy (β = .31, p = .021; p = .021 after FDR correction, Table 4, Figure 7), while perspective taking and prosocial tendencies did not relate to state empathy (Table 4). No trait measures of empathy and prosocial behavior were significantly related to prosocial behavior (Table 4). Subsequent exploratory analyses testing perspective taking, empathic concern, and prosocial tendencies' interaction by age and interaction by gender, predicting state empathy and prosocial behavior, revealed no significant interactions (see Tables 5-10).

Table 4 Trait Measures of Empathy and Prosocial Tendencies

	State Empathy		**Prosocial Behavior**	
	β	**SE**	**β**	**SE**
Age	0.01759	0.436	0.0552	0.123
Gender	**0.45825***	1.520	**0.4932***	0.428
Perspective Taking	-0.00306	1.668	-0.0333	0.471
Empathic Concern	**0.31084***	1.934	0.0562	0.599
Prosocial Tendencies	-0.03155	1.386	-0.0271	0.453

Note. **p < .05, ** p < .01, ***p< .001*

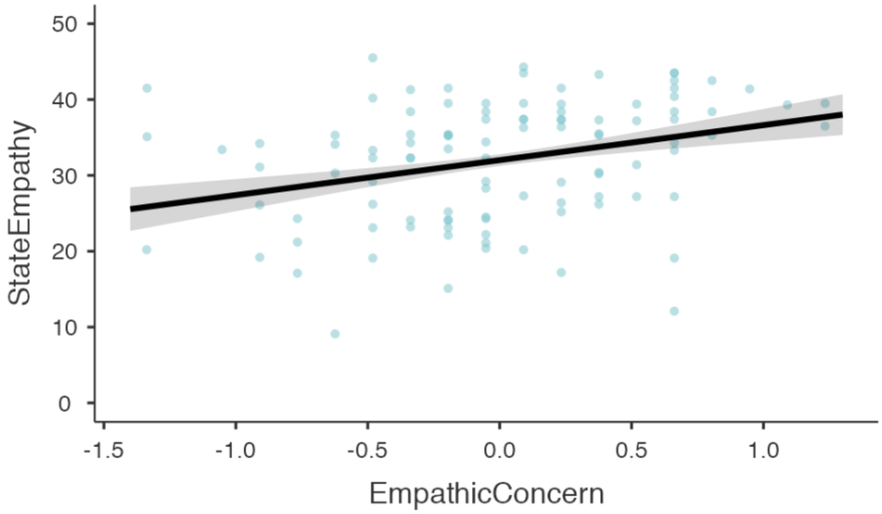


Figure 8 Empathic concern is a significant predictor of state empathy

Table 5 Perspective Taking x Age

	State Empathy		**Prosocial Behavior**	
	β	**SE**	**β**	**SE**
Age	0.01722	0.439	0.0555	0.124
Gender	0.45708	1.529	0.4840	0.431
Perspective Taking	-0.00666	1.703	-0.0470	0.479
Empathic Concern	0.30719	1.972	0.0466	0.605
Prosocial Tendencies	-0.02840	1.409	-0.0244	0.455
Perspective Taking x Age	0.01733	0.817	0.0734	0.240

Note. **p < .05, ** p < .01, ***p< .001*

Table 6 Perspective Taking x Age

	State Empathy		**Prosocial Behavior**	
	β	**SE**	**β**	**SE**
Age	0.01737	0.439	0.0508	0.123
Gender	0.45833	1.528	0.4927	0.429
Perspective Taking	-0.00327	1.677	-0.0276	0.471
Empathic Concern	0.31054	1.945	0.0391	0.603
Prosocial Tendencies	-0.03135	1.393	-0.0119	0.455
Perspective Taking x Gender	0.01296	2.540	0.2145	0.736

*Note. *p < .05, ** p < .01, ***p< .001*

Table 7 Empathic Concern x Age

	State Empathy		**Prosocial Behavior**	
	β	**SE**	**β**	**SE**
Age	0.01660	0.439	0.0478	0.123
Gender	0.45318	1.541	0.4461	0.437
Perspective Taking	-0.00764	1.704	-0.0545	0.475
Empathic Concern	0.30857	1.951	0.0386	0.602
Prosocial Tendencies	-0.02869	1.401	-0.0193	0.453
Empathic Concern x Age	0.02055	0.844	0.1340	0.256

*Note. *p < .05, ** p < .01, ***p< .001*

Table 8 Empathic Concern x Gender

	State Empathy		Prosocial Behavior	
	β	**SE**	**β**	**SE**
Age	0.02390	0.442	0.0629	0.126
Gender	0.45591	1.527	0.4912	0.431
Perspective Taking	-0.00739	1.679	-0.0416	0.478
Empathic Concern	0.32363	1.979	0.0711	0.616
Prosocial Tendencies	-0.03551	1.394	-0.0282	0.455
Empathic Concern x Gender	-0.09464	2.820	-0.0945	0.815

*Note. *p < .05, ** p < .01, ***p< .001*

Table 9 Prosocial Tendencies x Age

	State Empathy		Prosocial Behavior	
	β	**SE**	**β**	**SE**
Age	0.01050	0.440	0.0363	0.123
Gender	0.44641	1.529	0.4412	0.429
Perspective Taking	-0.00733	1.674	-0.0524	0.468
Empathic Concern	0.30503	1.942	0.0488	0.594
Prosocial Tendencies	-0.02448	1.393	-0.0300	0.449
Prosocial Tendencies x Age	0.07324	0.620	0.1807	0.185

*Note. *p < .05, ** p < .01, ***p< .001*

Table 10 Prosocial Tendencies x Age

	State Empathy		Prosocial Behavior	
	β	**SE**	**β**	**SE**
Age	0.00875	0.438	0.0519	0.126
Gender	0.46248	1.521	0.4947	0.432
Perspective Taking	0.00640	1.673	-0.0288	0.484
Empathic Concern	0.31618	1.936	0.0551	0.603
Prosocial Tendencies	-0.05516	1.411	-0.0315	0.464
Prosocial Tendencies x Gender	0.18845	2.102	0.0342	0.661

*Note. *p < .05, ** p < .01, ***p< .001*

Trait Predictors of Neural Activity

Multiple linear regression models were first run to examine the effects of trait measures of empathy and prosocial tendencies on Affective Pain, Mentalizing, and Prosocial Concern network activity, controlling for age and gender. There were no main effects of trait measures of empathy or prosocial tendencies on any of the network activity during exclusion (Table 11).

Exploratory analyses examining interactions with trait measures by age and trait measures by gender revealed no significant interactions predicting Mentalizing or Prosocial Concern network activity (Tables 11-17). The Affective Pain network showed significant empathic concern by gender (β = -.48, p = .02; p = .130 after FDR correction, Table 12) and significant perspective taking by gender (β = -.54, p = .007; p = .045 after FDR correction, Table 14) interactions. Simple effects analyses revealed that as boys increased in levels of self-reported empathic concern, they increased in activation of the Affective Pain network (β = .56, p = .004), while girls showed no relationship between empathic concern and Affective Pain network activity (β = .079, p = .617; Figure 8). However, this result did not pass FDR correction. The perspective taking by gender interaction followed a similar pattern – as boys increased in self-reported perspective taking, they showed increased activation in the Affective Pain network (β = .307, p = .056), while girls showed no relationship between perspective taking and Affective Pain network activity (β = -.23, p = .168, Figure 9). Girls low in perspective taking (5th percentile, M = 1.57) showed significantly greater activation in the Affective Pain network compared to boys in the 5th percentile on perspective taking (β = .88, p = .018). However, this significant gender difference was flipped for participants scoring higher in perspective taking (95th percentile, M = 3.43), such that boys were showing significantly greater activation in the Affective Pain network compared to girls (β = -.81, p = .027). There were no observed gender differences for those with average perspective taking scores (β = -.03, p = .862).

Table 11. Trait Measures of Empathy and Prosocial Tendencies

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	-0.00421	0.0418	-0.1059	0.0505	0.0507	0.0362
Gender	0.03051	0.1452	0.3587	0.1757	-0.1596	0.1261
Empathic Concern	0.25481	0.1808	0.2415	0.2189	0.1546	0.1599
Perspective Taking	0.05436	0.1635	-0.0325	0.1978	-0.0967	0.1416
Prosocial Tendencies	-0.24810	0.1337	-0.0773	0.1618	0.1387	0.1162

Note. **p < .05, ** p < .01, ***p< .001*

Table 12 Empathic Concern x Gender

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.0358	0.0414	-0.0830	0.0510	0.0437	0.0370
Gender	0.0161	0.1418	0.3505	0.1750	-0.1571	0.1268
Empathic Concern	0.3180	0.1799	0.2777	0.2219	0.1473	0.1623
Perspective Taking	0.0287	0.1602	-0.0472	0.1976	-0.0918	0.1430
Prosocial Tendencies	-0.2678	0.1308	-0.0886	0.1615	0.1403	0.1168
Empathic Concern x Gender	**-0.4785***	**0.2577**	-0.2737	0.3180	0.0739	0.2350

Note. **p < .05, ** p < .01, ***p< .001*

Table 13 Empathic Concern x Age

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.00392	0.0420	-0.1136	0.0508	0.0467	0.0365
Gender	0.05815	0.1471	0.3325	0.1781	-0.1752	0.1286
Empathic Concern	0.26243	0.1814	0.2343	0.2196	0.1537	0.1607
Perspective Taking	0.07385	0.1659	-0.0511	0.2008	-0.1057	0.1439
Prosocial Tendencies	-0.26057	0.1346	-0.0655	0.1630	0.1434	0.1171
Empathic Concern x Age	-0.09463	0.0784	0.0900	0.0949	0.0468	0.0694

Note. **p < .05, ** p < .01, ***p< .001*

Table 14 Perspective Taking x Gender

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.00410	0.0404	-0.1001	0.0499	0.0513	0.0364
Gender	0.02740	0.1403	0.3566	0.1733	-0.1598	0.1268
Empathic Concern	0.26813	0.1749	0.2508	0.2160	0.1545	0.1608
Perspective Taking	0.03822	0.1581	-0.0438	0.1953	-0.0977	0.1425
Prosocial Tendencies	-0.24214	0.1293	-0.0732	0.1596	0.1394	0.1169
Perspective Taking x Gender	**-0.53725****	**0.2349**	-0.3743	0.2901	-0.0277	0.2136

*Note. *p < .05, ** p < .01, ***p< .001*

Table 15 Perspective Taking x Age

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.00263	0.0419	-0.1085	0.0509	0.05011	0.0365
Gender	0.03472	0.1454	0.3571	0.1766	-0.16019	0.1269
Empathic Concern	0.27475	0.1835	0.2340	0.2229	0.15306	0.1623
Perspective Taking	0.07678	0.1668	-0.0411	0.2025	-0.09873	0.1449
Prosocial Tendencies	-0.27243	0.1368	-0.0681	0.1661	0.14083	0.1190
Perspective Taking x Age	-0.09766	0.0788	0.0372	0.0957	0.00897	0.0686

*Note. *p < .05, ** p < .01, ***p< .001*

Table 16 Prosocial Tendencies x Gender

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.0172	0.0417	-0.0957	0.0511	0.0474	0.0367
Gender	0.0218	0.1440	0.3546	0.1761	-0.1585	0.1268
Empathic Concern	0.2446	0.1795	0.2367	0.2195	0.1567	0.1611
Perspective Taking	0.0395	0.1624	-0.0396	0.1987	-0.0943	0.1427
Prosocial Tendencies	-0.2106	0.1345	-0.0596	0.1645	0.1328	0.1187
Prosocial Tendencies x Gender	-0.3306	0.1976	-0.1565	0.2417	0.0480	0.1737

Note. **p < .05, ** p < .01, ***p< .001*

Table 17 Prosocial Tendencies x Age

	Affective Pain		**Mentalizing**		**Prosocial Concern**	
(Intercept)	**β**	**SE**	**β**	**SE**	**β**	**SE**
Age	0.00754	0.0422	-0.1219	0.0509	0.0551	0.0367
Gender	0.05068	0.1463	0.3312	0.1764	-0.1517	0.1276
Empathic Concern	0.26237	0.1814	0.2312	0.2188	0.1565	0.1609
Perspective Taking	0.05244	0.1637	-0.0299	0.1974	-0.0977	0.1423
Prosocial Tendencies	-0.25197	0.1340	-0.0721	0.1616	0.1377	0.1168
Prosocial Tendencies x Age	-0.09385	0.0599	0.1281	0.0722	-0.0351	0.0520

Note. **p < .05, ** p < .01, ***p< .001*

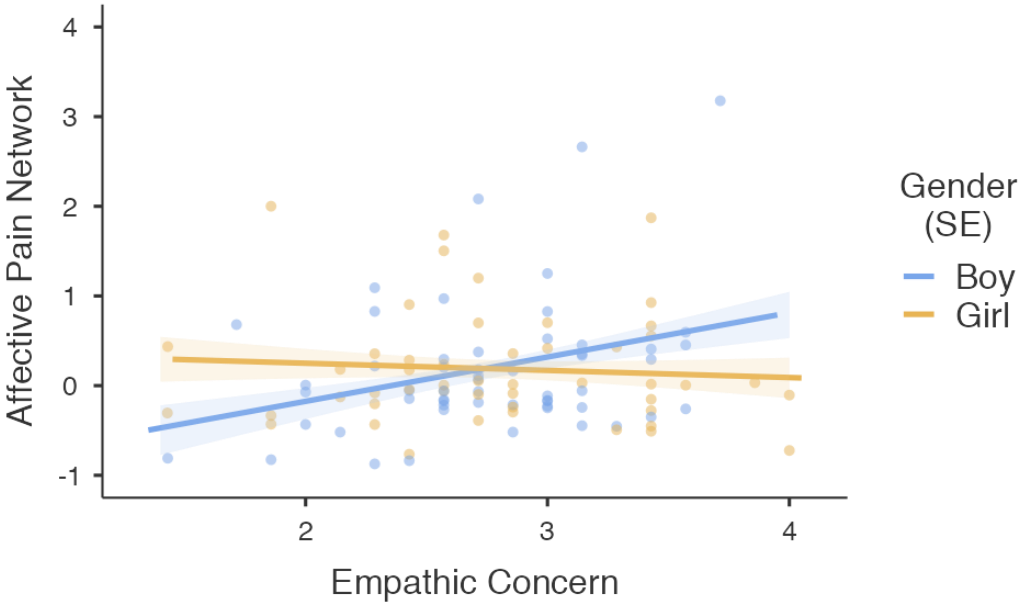


Figure 9 Empathic Concern by Gender interaction predicting Affective Pain Network activity

As reports of empathic concern increased for boys, activation in the Affective Pain network during exclusion vs inclusion increased. This result did not pass FDR correction.

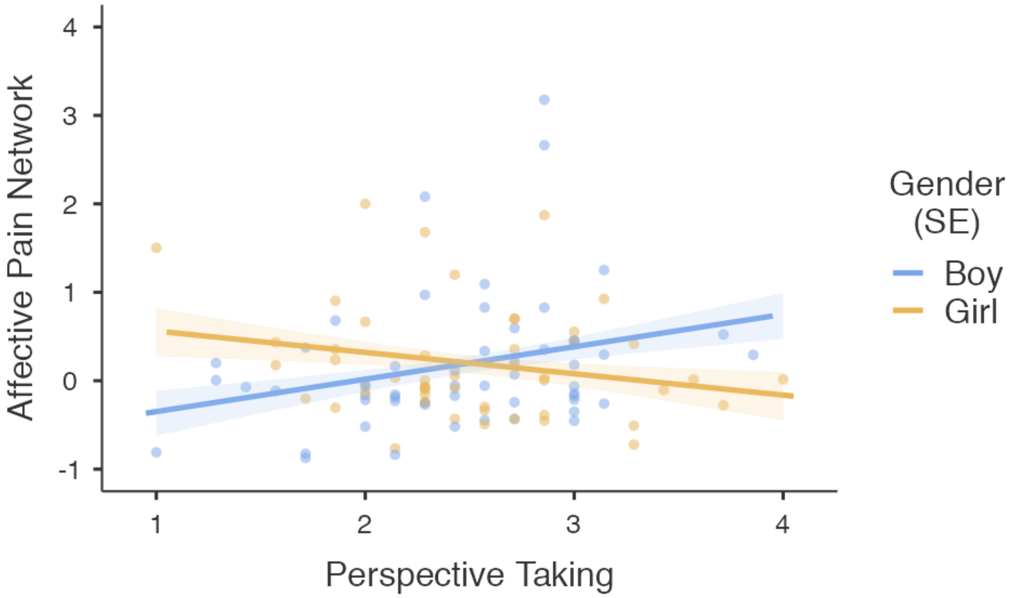


Figure 10 Perspective Taking by Gender interaction predicting Affective Pain network activity *Significant gender differences at both low and high levels of perspective taking, such that girls with low scores on perspective taking show significantly greater activation in the Affective Pain network than boys at low scores of perspective taking, but boys at high scores of perspective taking show significantly greater activation in the Affective Pain network than girls at high levels of perspective taking.*

Neural Predictors of State Empathy and Prosocial Behavior

Analyses revealed no significant main effects of Affective Pain, Mentalizing, or Prosocial Concern networks on state empathy or prosocial behavior, controlling for age and gender (Table 18). Subsequent analyses testing network by age and network by gender interactions found no significant Affective Pain x gender (Table 19), Affective Pain x age (Table 20), Mentalizing x gender (Table 21), Mentalizing x age (Table 22) or Prosocial Concern x gender (Table 23) interactions predicting state empathy or prosocial behavior.

While there were no interactions with network activity and gender predicting state empathy or prosocial behavior *(ps > .262)*, and no interaction with Mentalizing or Affective Pain network and age *(ps > .11)*, analyses revealed a significant Prosocial Concern by age interaction (β = .24, p = .026, p = .039 after FDR correction) predicting prosocial behavior (Table 24). Simple effects analyses revealed that for older adolescents, there is a significant linear relationship between Prosocial Network activity and degree of prosocial behavior, for 15-year-olds (β = .364, p = .032), 16-year-olds (β = .503, p = .021), and 17-year-olds (β = .643, p = .019), that does not exist for younger participants, like 11 (β = -.19, p = .271) or 13-year-olds (β = .08, p = .484; see Figure 11).

Table 18 Main effects of Networks

	State Empathy		**Prosocial Behavior**	
	β	**SE**	**β**	**SE**
Age	0.03665	0.424	0.07314	0.114
Gender	0.47070	1.528	0.38684	0.409
Affective Pain	-0.03529	1.225	0.00360	0.337
Mentalizing	-0.00384	1.321	-0.11469	0.344
Prosocial Concern	0.05926	1.485	0.09884	0.389

Note. **p < .05, ** p < .01, ***p< .001*

Table 19 Affective Pain x Gender

	State Empathy		Prosocial Behavior	
(Intercept)	**B**	**SE**	**β**	**SE**
Age	0.0248	0.421	0.0808	0.114
Gender	0.4688	1.513	0.3928	0.409
Affective Pain	-0.0143	1.219	-0.0218	0.341
Mentalizing	-0.0457	1.337	-0.0864	0.351
Prosocial Concern	0.0527	1.472	0.0964	0.389
Affective Pain x Gender	-0.3309	2.155	0.2392	0.591

Note. **p* < .05, ** *p* < .01, ****p*< .001

Table 20 Affective Pain x Age

	State Empathy		Prosocial Behavior	
(Intercept)	**β**	**SE**	**β**	**SE**
Age	0.0355	0.426	0.07379	0.114
Gender	0.4603	1.541	0.38967	0.412
Affective Pain	-0.0240	1.246	0.00193	0.339
Mentalizing	-0.0160	1.352	-0.10635	0.364
Prosocial Concern	0.0631	1.493	0.09603	0.394
Affective Pain x Age	-0.0552	0.688	0.02424	0.185

Note. **p* < .05, ** *p* < .01, ****p*< .001

Table 21 Mentalizing x Gender

	State Empathy		**Prosocial Behavior**	
(Intercept)	**β**	**SE**	**β**	**SE**
Age	0.0319	0.422	0.07501	0.114
Gender	0.4734	1.520	0.38980	0.411
Affective Pain	-0.0331	1.219	-0.00748	0.343
Mentalizing	-0.0157	1.318	-0.11167	0.346
Prosocial Concern	0.0700	1.480	0.09302	0.393
Mentalizing x Gender	-0.2758	1.748	0.10482	0.543

*Note. *p < .05, ** p < .01, ***p< .001*

Table 22 Mentalizing x Age

	State Empathy		**Prosocial Behavior**	
(Intercept)	**β**	**SE**	**β**	**SE**
Age	0.03672	0.426	0.0707	0.113
Gender	0.47395	1.547	0.4220	0.408
Affective Pain	-0.04221	1.320	-0.0435	0.341
Mentalizing	-0.00118	1.346	-0.0754	0.348
Prosocial Concern	0.05892	1.492	0.0906	0.386
Mentalizing x Age	0.01544	0.606	0.1848	0.162

*Note. *p < .05, ** p < .01, ***p< .001*

Table 23 Prosocial Concern x Gender

	State Empathy		**Prosocial Behavior**	
(Intercept)	**β**	**SE**	**β**	**SE**
Age	0.0341	0.156	0.07299	0.114
Gender	0.4697	3.768	0.38566	0.412
Affective Pain	-0.0281	-0.261	0.00680	0.344
Mentalizing	-0.0157	-0.180	-0.11615	0.348
Prosocial Concern	0.0654	0.853	0.09947	0.392
Prosocial Concern x Gender	-0.1414	-1.844	-0.02718	0.677

*Note. *p < .05, ** p < .01, ***p< .001*

Table 24 Prosocial Concern x Age

	State Empathy		**Prosocial Behavior**	
(Intercept)	**β**	**SE**	**β**	**SE**
Age	0.03652	0.426	0.0647	0.111
Gender	0.47203	1.546	0.4373	0.402
Affective Pain	-0.03768	1.291	-0.0616	0.337
Mentalizing	-0.00372	1.327	-0.1166	0.337
Prosocial Concern	0.06094	1.540	0.1755	0.396
Prosocial Concern x Age	**0.00602***	**0.782**	0.2446	0.197

*Note. *p < .05, ** p < .01, ***p< .001*

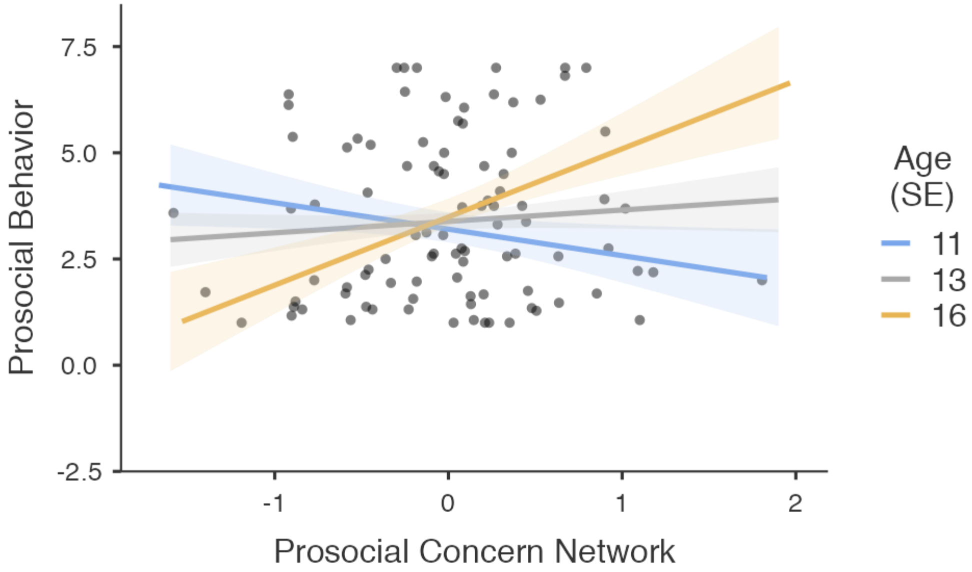


Figure 11 Prosocial Concern Network by age interaction predicting prosocial behavior

Older adolescents (15-17 years old) showed a significant relationship between Prosocial Concern network activity while viewing the exclusion and subsequent prosocial behavior in their messages to the players of the game, such that the more Prosocial Concern network activity during exclusion, the more prosocial their messages were.

VII. Discussion

Overall, results of the current study revealed interesting insights into how empathy relates to prosocial behavior, and how gender differences play a role in this. Firstly, while trait levels of empathic concern, perspective taking, or prosocial tendencies were not predictive of state empathy or prosocial behavior in response to viewing the exclusion, empathic concern was a significant predictor of state empathy, which was viewed as an outcome variable in the current investigation. While there was no effect of age or gender on trait empathic concern or perspective taking, gender differences in self-reported prosocial tendencies became significant by age 15, such that girls started reporting greater prosocial tendencies than boys (though this finding did not pass FDR correction). This gender difference was more consistently reflected, across all ages, in empathy and prosocial measures related to the experimental task – girls reported feeling greater levels of state empathy in response to viewing the social exclusion of a same-aged peer and were more prosocial in their messages to the players as well (though the gender difference in prosocial behavior did not pass FDR correction).

As for neuroimaging findings, both Mentalizing and Affective Pain networks showed significant activation during the viewing of a social exclusion (vs. inclusion) across the entire sample (while Prosocial Concern network activity was not significant). While girls showed significantly greater activation in the Mentalizing network while viewing the exclusion, gender differences in Affective Pain network activity arose based on individual differences in perspective taking. Amongst the participants scoring low in perspective taking, girls showed significantly greater activation in the Affective Pain network compared to boys. However, amongst participants high in perspective taking, this relationship flipped – boys scoring high in perspective taking showed significantly greater activation in the Affective Pain network compared to girls high in perspective taking. Finally, while not significantly activated across the whole sample during exclusion, the Prosocial Concern network became important in predicting subsequent prosocial behavior, specifically for older adolescents (15 to 17-year-olds), whose prosociality was significantly related to neural activation in this network.

Gender differences in the current report are consistent with previous findings, such that girls often show higher levels of empathy and greater tendency for prosocial behavior compared to boys, particularly in self-reported measures (Christov-Moore et al., 2014). While there is evidence, though inconsistent, for gender differences in empathy showing up as early as infancy and amongst toddlers, these differences appear to widen with age, as gender differences in empathy appear to increasingly diverge in adolescence, peaking around the time of puberty (Balk, 1995; Galambos et al.,1991; Lam et al., 2012). However, when comparing self-report measures of empathy to gender or sex differences in neural responses, the gender differences in empathy are inconsistent. For example, in one study measuring both self-reported trait empathy along with neurophysiological measures of empathic arousal, the gender difference in self-reported trait empathy was not reflected in neural responses (Michalska et al., 2013).

Gender differences in the current investigation largely arose from self-report and behavioral measures of empathy and prosocial behavior. On the one hand, the widening of gender differences in self-report and behavioral measures of empathy and prosocial behavior could be explained by cultural and societal expectations, i.e. the gender intensification theory (Hill & Lynch, 1983), such that boys and girls reaching puberty and undergoing physical changes may start to feel more compelled to act in line with stereotypical gender role expectations to be accepted by their peers (Fabes et al., 1999; Hill & Lynch, 1983; Huston & Alvarez, 1990). Given that gender differences in adolescence are most consistently seen via self-report measures, this may also be reflective of females' greater willingness to report on their empathic experiences (Michalska et al., 2013). Beyond a social explanation for gender differences, there may also be an underlying biological or hormonal explanation as well. Sex differences may have arisen from the evolutionary history of maternal care (Christov-Moore et al., 2014), such that it is more advantageous for females to have a greater sensitivity to nonverbal expressions and emotion recognition to care for their kin and ensure infant survival (Decety & Svetlova, 2012; Hampson et al., 2006). Additionally, one study found that females showed significantly larger volumes of gray matter in brain regions where networks of mirror neurons are located, underlying affective empathy, which was positively related to self-reported empathy scores (Cheng et al., 2009). In the current investigation, adolescent girls showed significantly greater activation in the Mentalizing network while viewing the social exclusion compared to boys. This may be reflective of differences in pubertal timing, as previous work has found pubertal development to be associated with increased emotional reactivity (Silk et al., 2009; Spear, 2009) and greater perspective-taking or mentalizing abilities (Keulers et al., 2010). Given the structural and functional reorganization of the brain that aligns with puberty (Blakemore, 2008; Blakemore et al., 2010), it is possible that puberty has an influence on the networks that underly empathy. Importantly, one study examining the effect of pubertal development on neural responding found that more activity in mentalizing regions while viewing another's social exclusion was associated with higher levels of physical maturation (i.e. pubertal development) at 13 years old (Masten et al., 2013). Given that the adolescent girls in the current sample were significantly more advanced in pubertal development compared to boys, the observed gender difference in mentalizing activity during exclusion may be related to the effect of puberty on mentalizing. Overall, given mixed evidence and multiple potential explanations for gender differences in empathy throughout the lifespan (and particularly in adolescence), these differences likely arise from an interplay of nature and nurture. However, given the reported sex differences measurable at birth and consistent across the lifespan, there may be an important evolutionary component driving these differences. Interestingly we see similar sex differences in empathy and prosocial behavior in animal models, such that while rats behave prosocially in response to a conspecific's distress, female rats were more likely to act prosocially than male rats (Bartal et al., 2011). This may suggest that even female rats are more empathic than males. Indeed, one study found that female mice, but not male, were more likely to approach a familiar same-sex cagemate who was in pain, compared to an unaffected cagemate, showing different behavioral responses depending on pain level (Langford et al., 2010). This sex-specific effect of pain-related social approach held even when observing female mice that lacked the oxytocin receptor. Scholars suggest that amongst mammals with highly sexually dimorphic parental care, such that females care for kin significantly more than males, males often show aggression toward unrelated pups (de Jong et al., 2009; Langford et al., 2010). However, amongst species with biparental investment like the prarie vole, males show enhanced prosocial behavior toward unrelated pups (Cushing & Wynne-Edwards, 2006; de Jong et al., 2009).

Apart from gender differences, we found that in general, viewing the exclusion of a same-aged peer related to significant activation in both Mentalizing and Affective Pain networks. While activation in the Mentalizing network is expected given the social and context-dependent nature of the task and has been frequently found in previous work using the same paradigm (Masten et al., 2010; Masten et al., 2011; Meyer et al., 2013), studies examining empathy for another's social pain has less frequently reported activation in the Affective Pain network across all participants. Instead, Affective Pain network activity (or the individual ROIs within this network) have been shown to be more sensitive to both the closeness with the victim and to individual differences in trait empathy. For example, dACC and AI activity only seemed to arise when participants were empathizing with the social exclusion of a close friend compared to stranger (Meyer et al., 2013), for those with high levels of trait empathy (Masten et al., 2011), or when activity in the affective pain related region of the AI was related to subsequent prosocial behavior (Masten et al., 2010; Masten et al., 2011). In light of the previous findings, it could be that the current cohort of participants felt closer, or a greater sense of kinship with the same-aged previous participant of the study that they believed to be playing the Cyberball game. It may also be that participants in the current study were generally higher on trait empathy, though it is difficult to compare due to differences in trait measures of empathy used across the studies. More generally, this finding may be reflective of cohort-specific effects, such that participants in this study are from a distinctly different Generation (Generation Z) that grew up in the presence of social media and technology, and connect more with each other virtually (Twenge, 2017). Perhaps viewing an online social exclusion is an even more salient experience for them compared to previous cohorts, and they are thus better able to both take on the perspective of an animated character being excluded online and share in their pain. Adolescents could also be calling up on their own past or present experiences with rejection, though the current study is not fit to make claims about this, as we did not collect a measure of rejection sensitivity. It would be important for future work to include this measure and investigate cohort or generational specific effects more intentionally.

Finally, while Mentalizing and Affective Pain networks were shown to be involved while viewing the exclusion (compared to inclusion), the Prosocial Concern network was the only network to be related to subsequent prosocial behavior for older adolescents (15 to 17-year-olds). The neural regions included in the Prosocial Concern network (SA and mOFC) are also regions involved in both mammalian and human caregiving systems (Inagaki & Eisenberger, 2012; Slotnick & Nigrosh, 1975). Some have suggested that for humans, the caregiving system remains immature until late adolescence, when the hormonal and neurobiological changes occurring during puberty push the caregiving system toward maturity (George & Solomon, 1996; Lenzi et al., 2015). Relatedly, Fullard and Reiling (1976) showed in an early study that when given the choice between pictures of adults or infants, children ages 7 to 12 preferred images of adults, while thereafter researchers witnessed an adult-like shift to preferences for pictures of infants corresponding with puberty and the ages at which boys and girls become capable of reproduction. This provides a potential explanation as to why we see the Prosocial Concern network begin to relate to or support prosocial behavior in older adolescence, as they may have a more mature caregiving system that can be more readily engaged to support their prosocial behaviors. However, more work investigating the maturation of the caregiving system, and how it supports prosocial behavior, is needed to strengthen this claim.

Additionally, while the Mentalizing and Affective Pain networks were not directly predictive of prosocial behavior in the current study, this does not imply that they do not have a role in influencing prosocial behavior. While it was beyond the scope of the current study, it is important to understand how these networks may be working together to produce a prosocial response, especially considering the significant Mentalizing and Affective Pain network activity that is related to viewing the exclusion in the current investigation. Given the nature of the Cyberball game, mentalizing is required to understand how the excluded player might be feeling. Additionally, while affective pain was not predictive, it might be needed to acknowledge the excluded player's suffering and motivate the participant towards a feeling of empathic or prosocial concern. Thus, it could be that some level of affective and mentalizing activity inspires prosocial concern, which predicts prosocial behavior. However, this study provides further evidence that prosocial concern and its distinct neural correlates play an important role in connecting empathy to prosocial behavior (Batson, 2012), and provides initial evidence for the idea that the prosocial concern network might be most influential in older adolescence, when the neural regions involved in a wider caregiving system are reaching or have reached maturity. This may have implications on most appropriate timing for successful empathy and compassion training interventions.

VII. References

Aknin, L. B., Broesch, T., Hamlin, J. K., & Van de Vondervoort, J. W. (2015). Prosocial behavior leads to happiness in a small-scale rural society. *Journal of experimental psychology: General*, *144*(4), 788.

Allemand, M., Steiger, A. E., & Fend, H. A. (2015). Empathy development in adolescence predicts social competencies in adulthood. *Journal of personality*, *83*(2), 229-241.

Ashar, Y. K., Andrews-Hanna, J. R., Dimidjian, S., & Wager, T. D. (2017). Empathic care and distress: predictive brain markers and dissociable brain systems. *Neuron*, *94*(6), 1263-1273.

Bartels, A., & Zeki, S. (2004). The neural correlates of maternal and romantic love. *Neuroimage*, *21*(3), 1155-1166.

Basch, M. F. (1983). Empathic understanding: A review of the concept and some theoretical considerations. *Journal of the American Psychoanalytic Association*, *31*(1), 101-126.

Balk, D. E. (1995). Adolescent development: early through late adolescence. Pacific Grove, CA: Brooks.

Bartal, I. B. A., Decety, J., & Mason, P. (2011). Empathy and pro-social behavior in rats. *Science*, *334*(6061), 1427-1430.

Batson, C. D. (2011). What's wrong with morality?. *Emotion Review*, *3*(3), 230-236.

Batson, C. D. (2012). A history of prosocial behavior research.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, *57*(1), 289-300.

Blair, R. J. R. (2005). Responding to the emotions of others: Dissociating forms of empathy through the study of typical and psychiatric populations. *Consciousness and cognition*, *14*(4), 698-718.

Blakemore, S. J. (2008). The social brain in adolescence. *Nature Reviews Neuroscience*, *9*(4), 267-277.

Blakemore, S. J. (2012). Imaging brain development: the adolescent brain. *Neuroimage*, *61*(2), 397-406.

Blakemore, S. J., Burnett, S., & Dahl, R. E. (2010). The role of puberty in the developing adolescent brain. *Human brain mapping*, *31*(6), 926-933.

Blakemore, S. J., & Mills, K. L. (2014). Is adolescence a sensitive period for sociocultural processing?. *Annual review of psychology*, *65*, 187-207.

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, J. D. (2002). Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron*, *33*(2), 301-311.

Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proceedings of the national Academy of Sciences*, *100*(9), 5497-5502.

Cheng, Y., Chou, K. H., Decety, J., Chen, I. Y., Hung, D., Tzeng, O. L., & Lin, C. P. (2009). Sex differences in the neuroanatomy of human mirror-neuron system: a voxel-based morphometric investigation. *Neuroscience, 158*(2), 713-720.

Christov-Moore, L., Simpson, E. A., Coudé, G., Grigaityte, K., Iacoboni, M., & Ferrari, P. F. (2014). Empathy: Gender effects in brain and behavior. *Neuroscience & biobehavioral reviews*, *46*, 604-627.

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature reviews neuroscience*, *13*(9), 636-650.

Cuff, B. M., Brown, S. J., Taylor, L., & Howat, D. J. (2016). Empathy: A review of the concept. *Emotion review*, *8*(2), 144-153.

Cushing, B. S., & Wynne-Edwards, K. E. (2006). Estrogen receptor-α distribution in male rodents is associated with social organization. *Journal of Comparative Neurology*, *494*(4), 595-605.

Davis, M. H. (1983). Measuring individual differences in empathy: evidence for a multidimensional approach. *Journal of personality and social psychology*, *44*(1), 113.

Davis, M. H., & Franzoi, S. L. (1991). Stability and change in adolescent self-consciousness and empathy. *Journal of research in Personality*, *25*(1), 70-87.

De Waal, F. B. (2007). Do animals feel empathy?. *Scientific American Mind*, *18*(6), 28-35.

De Waal, F. B. (2008). Putting the altruism back into altruism: The evolution of empathy. *Annu. Rev. Psychol.*, *59*, 279-300.

De Jong, T. R., Chauke, M., Harris, B. N., & Saltzman, W. (2009). From here to paternity: neural correlates of the onset of paternal behavior in California mice (Peromyscus californicus). *Hormones and behavior*, *56*(2), 220-231.

Dedovic, K., Slavich, G. M., Muscatell, K. A., Irwin, M. R., & Eisenberger, N. I. (2016). Dorsal anterior cingulate cortex responses to repeated social evaluative feedback in young women with and without a history of depression. *Frontiers in behavioral neuroscience*, *10*, 64.

Decety, J. (2010). The neurodevelopment of empathy in humans. *Developmental neuroscience*, *32*(4), 257-267.

Decety, J. (2011). The neuroevolution of empathy. *Annals of the New York Academy of Sciences*, *1231*(1), 35-45.

Decety, J., & Cowell, J. M. (2014). The complex relation between morality and empathy. *Trends in cognitive sciences*, *18*(7), 337-339.

Decety, J., & Grèzes, J. (2006). The power of simulation: imagining one's own and other's behavior. *Brain research*, *1079*(1), 4-14.

Decety, J., & Jackson, P. L. (2004). The functional architecture of human empathy. *Behavioral and cognitive neuroscience reviews*, *3*(2), 71-100.

Decety, J., & Lamm, C. (2009). The biological basis of empathy. *Handbook of neuroscience for the behavioral sciences. New York: John Wiley and Sons*, 940-957.

Decety, J., Lewis, K. L., & Cowell, J. M. (2015). Specific electrophysiological components disentangle affective sharing and empathic concern in psychopathy. *Journal of Neurophysiology*, *114*(1), 493-504.

Decety, J., & Meyer, M. (2008). From emotion resonance to empathic understanding: A social developmental neuroscience account. *Development and psychopathology*, *20*(4), 1053-1080.

Decety, J., & Michalska, K. J. (2010). Neurodevelopmental changes in the circuits underlying empathy and sympathy from childhood to adulthood. *Developmental science*, *13*(6), 886-899.

Decety, J., & Svetlova, M. (2012). Putting together phylogenetic and ontogenetic perspectives on empathy. *Developmental cognitive neuroscience*, *2*(1), 1-24.

Decety, J., & Yoder, K. J. (2016). Empathy and motivation for justice: Cognitive empathy and concern, but not emotional empathy, predict sensitivity to injustice for others. *Social neuroscience*, *11*(1), 1-14.

Desikan, R. S., Ségonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., ... & Killiany, R. J. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *Neuroimage*, *31*(3), 968-980.

Dirks, M. A., Dunfield, K. A., & Recchia, H. E. (2018). Prosocial behavior with peers: Intentions, outcomes, and interpersonal adjustment.

Dufour, N., Redcay, E., Young, L., Mavros, P. L., Moran, J. M., Triantafyllou, C., ... & Saxe, R. (2013). Similar brain activation during false belief tasks in a large sample of adults with and without autism. *PloS one*, *8*(9), e75468.

Dumontheil, I., Apperly, I. A., & Blakemore, S. J. (2010). Online usage of theory of mind continues to develop in late adolescence. *Developmental science*, *13*(2), 331-338.

Eisenberg, N., & Mussen, P. H. (1989). *The roots of prosocial behavior in children*. Cambridge University Press.

Eisenberg, N., Spinrad, T. L., & Sadovsky, A. (2006). Empathy-related responding in children.

Eisenberg, N., & Spinrad, T. L. (2014). Multidimensionality of prosocial behavior: Rethinking the conceptualization and development of prosocial behavior.

Eisenberger, N. I. (2012). The pain of social disconnection: examining the shared neural underpinnings of physical and social pain. *Nature reviews neuroscience*, *13*(6), 421-434.

Fabi, S., Weber, L. A., & Leuthold, H. (2019). Empathic concern and personal distress depend on situational but not dispositional factors. *PloS one, 14*(11), e0225102.

Fabes, R. A., Carlo, G., Kupanoff, K., & Laible, D. (1999). Early adolescence and prosocial/moral I: The role of individual processes. *The Journal of Early Adolescence*, *19*(1), 5-16.

Fan, Y., Duncan, N. W., de Greck, M., & Northoff, G. (2011). Is there a core neural network in empathy? An fMRI based quantitative meta-analysis. *Neuroscience & Biobehavioral Reviews*, *35*(3), 903-911.

Febo, M., Numan, M., & Ferris, C. F. (2005). Functional magnetic resonance imaging shows oxytocin activates brain regions associated with mother–pup bonding during suckling. *Journal of Neuroscience*, *25*(50), 11637-11644.

FeldmanHall, O., Dalgleish, T., Evans, D., & Mobbs, D. (2015). Empathic concern drives costly altruism. *Neuroimage*, *105*, 347-356.

Fullard, W., & Reiling, A. M. (1976). An investigation of Lorenz's" babyness". *Child Development*, 1191-1193.

Galambos, N. L., Almeida, D. M., & Petersen, A. C. (1990). Masculinity, femininity, and sex role attitudes in early adolescence: Exploring gender intensification. *Child development*, *61*(6), 1905-1914.

George, C., & Solomon, J. (1996). Representational models of relationships: Links between caregiving and attachment. *Infant Mental Health Journal: Official Publication of The World Association for Infant Mental Health*, *17*(3), 198-216.

Geraci, A., & Franchin, L. (2021). Is defensive behavior a subtype of prosocial behaviors?. *Frontiers in Psychology*, *12*, 678370.

Goodman, R. (1997). The Strengths and Difficulties Questionnaire: a research note. *Journal of child psychology and psychiatry*, *38*(5), 581-586.

Greimel, E., Schulte-Rüther, M., Fink, G. R., Piefke, M., Herpertz-Dahlmann, B., & Konrad, K. (2010). Development of neural correlates of empathy from childhood to early adulthood: an fMRI study in boys and adult men. *Journal of Neural Transmission*, *117*(6), 781-791.

Hall, J. A., & Schwartz, R. (2019). Empathy present and future. *The Journal of social psychology*, *159*(3), 225-243.

Hampson, E., van Anders, S. M., & Mullin, L. I. (2006). A female advantage in the recognition of emotional facial expressions: Test of an evolutionary hypothesis. *Evolution and human behavior*, *27*(6), 401-416.

Hastings, P. D., Miller, J. G., Kahle, S., & Zahn-Waxler, C. (2013). The neurobiological bases of empathic concern for others.

Hess, U., & Fischer, A. (2014). Emotional mimicry: Why and when we mimic emotions. *Social and personality psychology compass*, *8*(2), 45-57.

Hill, J. P., & Lynch, M. E. (1983). The intensification of gender-related role expectations during early adolescence. *Girls at puberty: Biological and psychosocial perspectives*, 201-228.

Hoffman, M. L. (1977). Sex differences in empathy and related behaviors. *Psychological bulletin*, *84*(4), 712.

Huston, A. C., & Alvarez, M. M. (1990). The socialization context of gender role development in early adolescence.

Inagaki, T. K., & Eisenberger, N. I. (2012). Neural correlates of giving support to a loved one. *Psychosomatic medicine*, *74*(1), 3-7.

Israelashvili, J., Sauter, D., & Fischer, A. (2020). Two facets of affective empathy: Concern and distress have opposite relationships to emotion recognition. *Cognition and Emotion*, *34*(6), 1112-1122.

Jackson, P. L., Meltzoff, A. N., & Decety, J. (2005). How do we perceive the pain of others? A window into the neural processes involved in empathy. *Neuroimage*, *24*(3), 771-779.

Jackson, P. L., Rainville, P., & Decety, J. (2006). To what extent do we share the pain of others? Insight from the neural bases of pain empathy. *Pain*, *125*(1), 5-9.

Jolliffe, D., & Farrington, D. P. (2006). Examining the relationship between low empathy and bullying. *Aggressive Behavior: Official Journal of the International Society for Research on Aggression*, *32*(6), 540-550.

Jordan, M. R., Amir, D., & Bloom, P. (2016). Are empathy and concern psychologically distinct?. *Emotion*, *16*(8), 1107.

Karan, M., Lazar, L., Leschak, C. J., Galván, A., Eisenberger, N. I., Uy, J. P., ... & Fuligni, A. J. (2022). Giving to others and neural processing during adolescence. *Developmental Cognitive Neuroscience*, *56*, 101128.

Keulers, E. H., Evers, E. A., Stiers, P., & Jolles, J. (2010). Age, sex, and pubertal phase influence mentalizing about emotions and actions in adolescents. *Developmental Neuropsychology*, *35*(5), 555-569.

Kilford, E. J., Garrett, E., & Blakemore, S. J. (2016). The development of social cognition in adolescence:An integrated perspective. *Neuroscience & Biobehavioral Reviews*, *70*, 106-120.

Killgore, W. D., & Yurgelun-Todd, D. A. (2007). Unconscious processing of facial affect in children and adolescents. *Social Neuroscience*, *2*(1), 28-47.

Klimecki, O. M., Leiberg, S., Lamm, C., & Singer, T. (2013). Functional neural plasticity and associated changes in positive affect after compassion training. *Cerebral cortex*, *23*(7), 1552-1561.

Kringelbach, M. L., Lehtonen, A., Squire, S., Harvey, A. G., Craske, M. G., Holliday, I. E., ... & Stein, A. (2008). A specific and rapid neural signature for parental instinct. *PloS one*, *3*(2), e1664.

Lam, C. B., Solmeyer, A. R., & McHale, S. M. (2012). Sibling relationships and empathy across the transition to adolescence. *Journal of youth and adolescence*, *41*, 1657-1670.

Lambe, L. J., & Craig, W. M. (2020). Peer defending as a multidimensional behavior: Development and validation of the defending behaviors scale. *Journal of School Psychology*, *78*, 38-53.

Lamm, C., Decety, J., & Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage*, *54*(3), 2492-2502.

Lamm, C., Nusbaum, H. C., Meltzoff, A. N., & Decety, J. (2007). What are you feeling? Using functional magnetic resonance imaging to assess the modulation of sensory and affective responses during empathy for pain. *PloS one*, *2*(12), e1292.

Langford, D. J., Tuttle, A. H., Brown, K., Deschenes, S., Fischer, D. B., Mutso, A., ... & Sternberg, W. F. (2010). Social approach to pain in laboratory mice. *Social neuroscience*, *5*(2), 163-170.

Lenzi, D., Trentini, C., Tambelli, R., & Pantano, P. (2015). Neural basis of attachment-caregiving systems interaction: insights from neuroimaging studies. *Frontiers in psychology*, *6*, 1241.

Lockwood, P. L. (2016). The anatomy of empathy: Vicarious experience and disorders of social cognition. *Behavioural brain research*, *311*, 255-266

Lorberbaum, J. P., Newman, J. D., Dubno, J. R., Horwitz, A. R., Nahas, Z., Teneback, C. C., ... & George, M. S. (1999). Feasibility of using fMRI to study mothers responding to infant cries. *Depression and anxiety*, *10*(3), 99-104.

Maldjian, J. A., Laurienti, P. J., Kraft, R. A., & Burdette, J. H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage*, *19*(3), 1233-1239.

Marsh, A. A. (2016). Neural, cognitive, and evolutionary foundations of human altruism. *Wiley Interdisciplinary Reviews: Cognitive Science*, *7*(1), 59-71.

Marsh, A. A., Stoycos, S. A., Brethel-Haurwitz, K. M., Robinson, P., VanMeter, J. W., & Cardinale, E. M. (2014). Neural and cognitive characteristics of extraordinary altruists. *Proceedings of the National Academy of Sciences*, *111*(42), 15036-15041.

Masten, C. L., Eisenberger, N. I., Pfeifer, J. H., Colich, N. L., & Dapretto, M. (2013). Associations among pubertal development, empathic ability, and neural responses while witnessing peer rejection in adolescence. *Child Development*, *84*(4), 1338-1354.

Masten, C. L., Eisenberger, N. I., Pfeifer, J. H., & Dapretto, M. (2010). Witnessing peer rejection during early adolescence: Neural correlates of empathy for experiences of social exclusion. *Social neuroscience*, *5*(5-6), 496-507.

Masten, C. L., Morelli, S. A., & Eisenberger, N. I. (2011). An fMRI investigation of empathy for ‘social pain’and subsequent prosocial behavior. *Neuroimage*, *55*(1), 381-388.

Mella, N., Studer, J., Gilet, A. L., & Labouvie-Vief, G. (2012). Empathy for pain from adolescence through adulthood: an event-related brain potential study. *Frontiers in Psychology*, *3*, 501.

Meyer, M. L., Masten, C. L., Ma, Y., Wang, C., Shi, Z., Eisenberger, N. I., & Han, S. (2013). Empathy for the social suffering of friends and strangers recruits distinct patterns of brain activation. *Social cognitive and affective neuroscience*, *8*(4), 446-454.

Michalska, K. J., Kinzler, K. D., & Decety, J. (2013). Age-related sex differences in explicit measures of empathy do not predict brain responses across childhood and adolescence. *Developmental cognitive neuroscience*, *3*, 22-32.

Mills, K. L., Lalonde, F., Clasen, L. S., Giedd, J. N., & Blakemore, S. J. (2014). Developmental changes in the structure of the social brain in late childhood and adolescence. *Social cognitive and affective neuroscience*, *9*(1), 123-131.

Moll, J., Krueger, F., Zahn, R., Pardini, M., de Oliveira-Souza, R., & Grafman, J. (2006). Human fronto–mesolimbic networks guide decisions about charitable donation. *Proceedings of the National Academy of Sciences*, *103*(42), 15623-15628.

Moll, J., Zahn, R., de Oliveira-Souza, R., Bramati, I. E., Krueger, F., Tura, B., ... & Grafman, J. (2011). Impairment of prosocial sentiments is associated with frontopolar and septal damage in frontotemporal dementia. *Neuroimage*, *54*(2), 1735-1742.

Morelli, S. A., Rameson, L. T., & Lieberman, M. D. (2014). The neural components of empathy: predicting daily prosocial behavior. *Social cognitive and affective neuroscience*, *9*(1), 39-47.

Nagy, E., Kompagne, H., Orvos, H., & Pal, A. (2007). Gender-related differences in neonatal imitation. *Infant and Child Development: An International Journal of Research and Practice*, *16*(3), 267-276.

Nieuwenhuys, R., Voogd, J., Van Huijzen, C., Nieuwenhuys, R., Voogd, J., & Van Huijzen, C. (1978). Functional systems. *The Human Central Nervous System: A Synopsis and Atlas*, 107-226.

Ochsner, K. (2013). The role of control in emotion, emotion regulation, and empathy. In *Changing emotions* (pp. 157-165). Psychology Press.

Peplak, J., & Malti, T. (2021). Toward generalized concern: The development of compassion and links to kind orientations. *Journal of Adolescent Research*, 07435584211007840.

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of youth and adolescence*, *17*(2), 117-133.

Preston, S. D. (2013). The origins of altruism in offspring care. *Psychological bulletin*, *139*(6), 1305.

Preston, S. D., & De Waal, F. B. (2002). Empathy: Its ultimate and proximate bases. *Behavioral and brain sciences*, *25*(1), 1-20.

Reniers, R. L., Corcoran, R., Drake, R., Shryane, N. M., & Völlm, B. A. (2011). The QCAE: A questionnaire of cognitive and affective empathy. *Journal of personality assessment*, *93*(1), 84-95.

Rilling, J. K. (2013). The neural and hormonal bases of human parentalcare. *Neuropsychologia*, *51*(4), 731-747.

Ruby, P., & Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of cognitive neuroscience*, *16*(6), 988-999.

Schulte-Rüther, M., Greimel, E., Piefke, M., Kamp-Becker, I., Remschmidt, H., Fink, G. R., ... & Konrad, K. (2014). Age-dependent changes in the neural substrates of empathy in autism spectrum disorder. Social cognitive and affective neuroscience, 9(8), 1118-1126.

Schwenck, C., Göhle, B., Hauf, J., Warnke, A., Freitag, C. M., & Schneider, W. (2014). Cognitive and emotional empathy in typically developing children: The influence of age, gender, and intelligence. *European Journal of Developmental Psychology*, *11*(1), 63-76.

Schnell, K., Bluschke, S., Konradt, B., & Walter, H. (2011). Functional relations of empathy and mentalizing: an fMRI study on the neural basis of cognitive empathy. *Neuroimage*, *54*(2), 1743-1754

Shamay-Tsoory, S. G. (2011). The neural bases for empathy. *The Neuroscientist*, *17*(1), 18-24.

Shamay-Tsoory, S. G., Aharon-Peretz, J., & Perry, D. (2009). Two systems for empathy: a double dissociation between emotional and cognitive empathy in inferior frontal gyrus versus ventromedial prefrontal lesions. *Brain*, *132*(3), 617-627.

Shamay-Tsoory, S. G., Tomer, R., Goldsher, D., Berger, B. D., & Aharon-Peretz, J. (2004). Impairment in cognitive and affective empathy in patients with brain lesions: anatomical and cognitive correlates. *Journal of clinical and experimental neuropsychology*, *26*(8), 1113-1127.

Sheehan, T., & Numan, M. (2000). The septal region and social behavior. In *The behavioral neuroscience of the septal region* (pp. 175-209). Springer, New York, NY.

Silk, J. S., Siegle, G. J., Whalen, D. J., Ostapenko, L. J., Ladouceur, C. D., & Dahl, R. E. (2009). Pubertal changes in emotional information processing: Pupillary, behavioral, and subjective evidence during emotional word identification. *Development and psychopathology*, *21*(1), 7-26.

Simon-Thomas, E. R., Godzik, J., Castle, E., Antonenko, O., Ponz, A., Kogan, A., & Keltner, D. J. (2012). An fMRI study of caring vs self-focus during induced compassion and pride. *Social cognitive and affective neuroscience*, *7*(6), 635-648.

Singer, T., & Frith, C. (2005). The painful side of empathy. *Nature neuroscience*, *8*(7), 845-846.

Singer, T., & Lamm, C. (2009). The social neuroscience of empathy. *Annals of the New York Academy of Sciences*, *1156*(1), 81-96.

Singer, T., Seymour, B., O'doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science*, *303*(5661), 1157-1162.

Singer, T., Seymour, B., O'Doherty, J. P., Stephan, K. E., Dolan, R. J., & Frith, C. D. (2006). Empathic neural responses are modulated by the perceived fairness of others. *Nature*, *439*(7075), 466-469.

Slavich, G. M., Way, B. M., Eisenberger, N. I., & Taylor, S. E. (2010). Neural sensitivity to social rejection is associated with inflammatory responses to social stress. *Proceedings of the national academy of sciences*, *107*(33), 14817-14822.

Slotnick, B. M., & Nigrosh, B. J. (1975). Maternal behavior of mice with cingulate cortical, amygdala, or septal lesions. *Journal of Comparative and Physiological Psychology*, *88*(1), 118.

Spear, L. P. (2009). Heightened stress responsivity and emotional reactivity during pubertal maturation: Implications for psychopathology. *Development and psychopathology*, *21*(1), 87-97.

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in cognitive sciences*, *9*(2), 69-74.

Stevens, F., & Taber, K. (2021). The neuroscience of empathy and compassion in pro-social behavior. *Neuropsychologia*, *159*, 107925.

Strathearn, L., Fonagy, P., Amico, J., & Montague, P. R. (2009). Adult attachment predicts maternal brain and oxytocin response to infant cues. *Neuropsychopharmacology, 34*(13), 2655-2666.

Swick, D., Ashley, V., & Turken, U. (2008). Left inferior frontal gyrus is critical for response inhibition. *BMC neuroscience, 9*(1), 1-11.

Tousignant, B., Eugène, F., & Jackson, P. L. (2017). A developmental perspective on the neural bases of human empathy. *Infant Behavior and Development*, *48*, 5-12.

Tousignant, B., Eugène, F., Sirois, K., & Jackson, P. L. (2018). Difference in neural response to social exclusion observation and subsequent altruism between adolescents and adults. *Neuropsychologia*, *116*, 15-25.

Tusche, A., Böckler, A., Kanske, P., Trautwein, F. M., & Singer, T. (2016). Decoding the charitable brain: empathy, perspective taking, and attention shifts differentially predict altruistic giving. *Journal of Neuroscience, 36*(17), 4719-4732.

Twenge, J. M. (2017). *iGen: Why today's super-connected kids are growing up less rebellious, more tolerant, less happy--and completely unprepared for adulthood--and what that means for the rest of us*. Simon and Schuster.

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., ... & Joliot, M. (2002). Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. *Neuroimage*, *15*(1), 273-289.

Vachon, D. D., Lynam, D. R., & Johnson, J. A. (2014). The (non) relation between empathy and aggression: surprising results from a meta-analysis. *Psychological bulletin*, *140*(3), 751.

Vaish, A., Carpenter, M., & Tomasello, M. (2009). Sympathy through affective perspective taking and its relation to prosocial behavior in toddlers. *Developmental psychology*, *45*(2), 534.

Van der Graaff, J., Branje, S., De Wied, M., Hawk, S., Van Lier, P., & Meeus, W. (2014). Perspective taking and empathic concern in adolescence: gender differences in developmental changes. *Developmental psychology, 50*(3), 881.

Van der Graaff, J., Carlo, G., Crocetti, E., Koot, H. M., & Branje, S. (2018). Prosocial behavior in adolescence: gender differences in development and links with empathy. *Journal of youth and adolescence*, *47*(5), 1086-1099.

Walter, H. (2012). Social cognitive neuroscience of empathy: Concepts, circuits, and genes. *Emotion Review*, *4*(1), 9-17.

Way, B. M., Taylor, S. E., & Eisenberger, N. I. (2009). Variation in the μ-opioid receptor gene (OPRM1) is associated with dispositional and neural sensitivity to social rejection. *Proceedings of the National Academy of Sciences*, *106*(35), 15079-15084.

Weng, H. Y., Fox, A. S., Shackman, A. J., Stodola, D. E., Caldwell, J. Z., Olson, M. C., ... & Davidson, R. J. (2013). Compassion training alters altruism and neural responses to suffering. *Psychological science*, *24*(7), 1171-1180.

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. *Neuron*, *40*(3), 655-664.

Williams, K. D., Cheung, C. K., & Choi, W. (2000). Cyberostracism: effects of being ignored over the Internet. *Journal of personality and social psychology*, *79*(5), 748.

Winters, D. E., Pruitt, P. J., Fukui, S., Cyders, M. A., Pierce, B. J., Lay, K., & Damoiseaux, J. S. (2021). Network functional connectivity underlying dissociable cognitive and affective components of empathy in adolescence. *Neuropsychologia*, *156*, 107832.

Yarkoni, T., Poldrack, R. A., Nichols, T. E., Van Essen, D. C., & Wager, T. D. (2011). Large-scale automated synthesis of human functional neuroimaging data. *Nature methods*, *8*(8), 665-670.

Zahn, R., Moll, J., Paiva, M., Garrido, G., Krueger, F., Huey, E. D., & Grafman, J. (2009). The neural basis of human social values: evidence from functional MRI. *Cerebral cortex*, *19*(2), 276-283.

Zahn-Waxler, C., Radke-Yarrow, M., Wagner, E., & Chapman, M. (1992). Development of concern for others. *Developmental psychology*, *28*(1), 126.

Zaki, J., & Ochsner, K. N. (2012). The neuroscience of empathy: progress, pitfalls and promise. *Nature neuroscience*, *15*(5), 675-680.

Zaki, J., Weber, J., Bolger, N., & Ochsner, K. (2009). The neural bases of empathic accuracy. *Proceedings of the National Academy of Sciences*, *106*(27), 11382-11387.

Zelazo, P. D., Carlson, S. M., & Kesek, A. (2008). The development of executive function in childhood.