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Investigating Neural Mechanisms Associated With the Double Empathy Problem Using fNIRS Hyperscanning

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Psychology

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Abstract

The Double Empathy Problem posits that autistic social difficulties are due to differences in communication styles rather than an autistic deficit in theory of mind (ToM). We used fNIRS hyperscanning to examine whether neural synchrony in pairs with varying levels of autistic traits during social interactions supports the Double Empathy Problem. Participants with low and high autistic trait expression were paired creating High-High, Low-High, and Low-Low groups. Pairs completed two trials where they 1) listened to and 2) discussed stories that contained or lacked theory of mind elements, while brain activity was recorded within the ToM network. During conversation, High-High pairs were less synchronous than Low-High pairs, but more synchronous than Low-Low pairs. We found significant synchrony for High-High pairs in ToM network during three of four conditions. Although we failed to find evidence in support the Double Empathy Problem, our results provide evidence against autism-specific theory of mind deficits.

Keywords

Social Interaction, Autism, ASD, Hyperscanning, fNIRS, Neuroimaging, Theory of Mind, Double Empathy, Conversation, Neuroscience, Cognition, Social, Autistic traits, Neural synchrony, Inter-brain synchrony, Interpersonal synchrony

Summary for Lay Audience

One characteristic of autism is difficulty with social interactions. The Double Empathy Problem is a theory that autistic social difficulties are caused by differences in communication styles between autistic and non-autistic people, and not by autistic people being unable to understand things from another person's perspective (a skill called theory of mind). We used a method where two people's brains are scanned at the same time, called hyperscanning, to look at similarities in brain activity. This is called neural synchrony. Participants had high or low autistic traits, creating High-High, Low-High, and Low-Low pairs. Based on the Double Empathy Problem, we expected that people would have higher synchrony when talking to partners with similar traits. Pairs listened to and talked about two stories. Brain activity was recorded from temporo-parietal junction and prefrontal cortex, brain areas that are used for theory of mind. During conversation, we found less synchrony in High-High pairs than Low-High pairs overall, but more synchrony in High-High pairs than Low-Low pairs in several of the channels we recorded brain activity from. We found synchrony that was greater than zero for High-High pairs in the theory of mind brain areas during three of the four conditions. Results show evidence against theory of mind problems related to autism.

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Chapter 1

1 Introduction

Autism affects approximately 1 in 50 children in Canada (Ofner et al., 2018). Autism is characterized by restricted or repetitive behaviours, sensory processing difficulties, and social communication differences. Autistic people often show less reciprocity than neurotypical people during conversations. They also may not use nonverbal communication like eye contact or gestures as frequently or in the same way as neurotypical people (5th ed.; DSM-5; American Psychiatric Association, 2013). Autistic individuals sometimes have trouble socializing with others or developing relationships with others as a result of these differences. However, difficulties with social interactions may be due to mutual misunderstanding between autistic and neurotypical individuals rather than a deficit associated with autism, and idea known as the Double Empathy Problem (Milton, 2012). Studies of social behaviour and autistic experiences support the Double Empathy Problem. People appear to have more successful interactions with others who share their neurotype; participants also appear to be better at predicting the mental states of characters that behave similarly to someone of their own neurotype (Milton et al., 2022). However, the Double Empathy Problem has not been widely studied from a neuroscience perspective.

Examining neural mechanisms during social interaction can help us to understand the nature of autistic social communication. Currently, our understanding of the neural mechanisms underlying autistic social difficulties is limited. Many studies have examined brain areas thought to be linked to social cognition in autistic individuals, but many of these studies have been done in isolated settings (Schilbach, 2013). Studies that measure brain activity using an isolated approach may be missing important aspects of social cognition that are present during real-world interactions (Schilbach & Redcay, 2019). Measuring neural activity from only one person during real-time interactions can also result in missing information, since interactions are two-sided. Hyperscanning is one approach that can take into account both the nuances of live interaction and the two-sided nature of interactions. Hyperscanning records brain activity from all parties involved and

can be used during real-time interactions. Data can then be used to examine both individual and shared patterns in brain activity during socialization. The goal of my thesis is to determine whether the Double Empathy Problem is supported by the brain activity patterns of interacting partners with varying levels of autistic traits.

1.1 Autism and Theory of Mind

Theory of mind is the ability to understand one's own mental states and attribute mental states to others (Premack & Woodruff, 1978). Theory of mind is thought to be a core element of social interaction; it allows individuals to infer what others might be thinking and feeling, to modulate social responses. Theory of mind ability is tested in children using False Belief tasks (Baron-Cohen et al., 1985). In these tests, a child is presented with two dolls, for example, "Sally" and "Anne". Sally places a marble into a basket, then leaves the room. While she is gone, Anne moves the marble into a box. Sally then returns to look for her marble. The child is asked, "Where will Sally look for the marble?" If the child has theory of mind, they will understand that Sally doesn't know that Anne has moved the marble, so she will look for it in the basket. Typically developing children can correctly solve this False Belief task around age 4 (Wimmer & Perner, 1983). Past explanations have pointed to a lack of theory of mind as the reason for autistic social difficulties (Baron-Cohen et al., 1985). When autistic children were evaluated, it was initially reported that most could not pass False Belief tasks successfully until around age 10. Theory of mind abilities in autistic individuals have also been evaluated using several other types of tasks, including second order False Belief tasks, Strange Stories (Happé, 1994), the Reading the Mind in the Eyes test (Baron-Cohen et al., 2001), and the Animated Triangles task (Abell et al., 2000). Autistic groups in early studies showed marked deficits in performance on theory of mind tasks. Baron-Cohen et al. (1985) claimed that the inability to use theory of mind was a problem unique to autism, and that failure to use theory of mind caused social difficulties in autistic individuals. According to this explanation, theory of mind deficits must also be universal to all autistic people, since social communication difficulties are a shared characteristic. This explanation was widely accepted by the research community, and has been the foundation for many social cognition studies (Gernsbacher, 2018). However, upon closer

inspection, much of the current body of literature fails to support the core assumptions of the autistic theory of mind deficit hypothesis.

First, many studies have found evidence that theory of mind deficits lack both exclusivity to autism and universality. Theory of mind tasks are failed by children with many other conditions, including Down Syndrome (Zelazo et al., 1996), William's Syndrome (van Herwegen et al., 2013), cerebral palsy (Caillies et al., 2012), Prader-Willi syndrome (Lo et al., 2013), fragile X syndrome (Cornish et al., 2005), epilepsy (Raud et al., 2015), neurofibromatosis (Payne et al., 2016), specific language impairment (Loukusa et al., 2014), and even those exposed to prenatal maternal smoking (Reidy et al., 2013).

Children with impaired vision or hearing are also more likely to fail the false belief tasks (Brambring & Asbrock, 2010; Figueras-Costa & Harris, 2001). If theory of mind deficits were truly the cause of social impairments, then children with all of these conditions would show the same difficulties with social communication as autistic children – but this is not the case.

Additionally, typically developing children's performance on theory of mind tasks varies with several factors. Children who have fewer siblings (Jenkins & Astington, 1996), and fewer nearby adult relatives (Lewis et al., 1996) also tend to fail false belief tasks, suggesting that the development of theory of mind skills depends on a child's opportunity to socialize with family members. Performance on a battery of theory of mind tasks also varied significantly with the nature of sibling relationships (Hughes & Ensor, 2005). Social relationships within a child's family are highly variable in both autistic and neurotypical populations. Thus, both groups should show variation in theory of mind ability, and therefore variations in social communication skills, contrary to the autistic deficit hypothesis. Together, it seems that theory of mind deficits are not unique to autism.

Variations in theory of mind task performance may be attributable to the fact that theory of mind tasks rely on spoken language ability. Language ability appears to be a much better predictor of theory of mind performance than autism diagnosis. For example, vocabulary predicted False Belief task performance better than autism diagnosis (Lokusa

et al., 2014; Norbury, 2005). Theory of mind tasks also fail to predict autistic traits, in addition to many other measures of social adeptness such as: empathy and emotional understanding, everyday social skills, social attention, and peer relations (Gernsbacher & Yergeau, 2019). The only characteristic that was predicted by theory of mind task performance was language dexterity (Lombardo et al., 2015). Similar patterns were observed when scores on language measures were used as a predictor; vocabulary predicted False Belief task performance better than autism diagnosis (Lokusa et al., 2014; Norbury, 2005), and language comprehension was the only predictor of performance on the Strange Stories task (Shaked et al., 2006).

Linguistic ability as a predictor of theory of mind performance also provides a more accurate explanation for deficits that appear in non-autistic populations. Many of the factors that predicted theory of mind task performance in other populations are also associated with differences in spoken language ability, including Down Syndrome, specific language impairment, and impaired hearing. Typically developing children with poorer language skills had a greater association between false belief performance and family size, suggesting that interactions with siblings can compensate for weaker language ability when developing theory of mind (Jenkins & Astington, 1996). Variations in language ability have also been linked to socioeconomic status. Mothers with higher levels of education tend to use teaching practices with their children that lead to higher levels of language ability (Hoff & Tian, 2005). Typically developing children with lower socioeconomic status were more likely to fail theory of mind tasks, likely because of differences in language ability (Hughes & Ensor, 2005). Autism is often accompanied by communication impairments, which would account for findings that autistic individuals tended to perform worse on standard theory of mind tasks. However, if performance was due to impairments in communication in autistic individuals, this would suggest that theory of mind ability would covary with language abilities. This contradicts the original theory proposed by Baron-Cohen that theory of mind deficits are universal across autistic individuals.

In fact, many autistic children do pass theory of mind tasks such as first-order False Belief tasks (Buitelaar et al., 1999) and second-order False Belief tasks (Bauminger &

Kasari, 1999). Though it was originally proposed that a lack of theory of mind was something all autistic people share, and that this was a characteristic unique to autism, these statements are not supported by autistic participants' performance on different theory of mind tasks and evidence of theory of mind deficits in a variety of other populations.

In addition to lacking generalizability, differences in performance between autistic and non-autistic individuals have do not hold up to scientific rigor. An early study by Baron-Cohen et al. (1986) presented autistic and neurotypical children with non-verbal theory of mind tasks in an attempt to eliminate the effects of verbal ability. Children were asked to order three different sets of pictures, each of which was said to be more difficult than the last. Interestingly, neurotypical children performed poorly on the simplest picture set, with below 50% of children ordering the pictures correctly. Autistic and neurotypical children showed no difference in performance on the medium difficulty task. On the hardest task, neurotypical children performed near perfect and autistic children performed poorly. Differences in performance on the hardest task were classified as a “specific cognitive deficit” in autistic children, despite neurotypical children being unable to pass the easiest of these three tests.

Additionally, several researchers have attempted to replicate the differences in autistic performance on the most difficult theory of mind picture sequence, but have consistently found no significant differences between groups (Ozonoff et al., 1991; Oswald & Olendick, 1989; Buitelaar et al., 1999; Brent et al., 2004). Effect sizes in the replicated studies also consistently differed from the original findings; while the original study reported a large effect size ($d = -1.714$), the combined effect size of its replications was quite small ($d = -0.039$; Gernsbacher, 2018). Attempts to replicate the group differences found on Baron-Cohen's original first and second order False Belief tasks and several other 'advanced' theory of mind tasks were also unsuccessful (Gernsbacher & Yergeau, 2019). This may be because the original studies were underpowered. Seminal studies that found group differences in theory of mind performance used sample sizes that were not large enough to reliably test their hypotheses. For example, the non-verbal picture ordering task (Baron-Cohen et al., 1986), had a sample size of 21 autistic participants;

similarly, the original “Sally-Anne” False Belief test used a sample size of 20 autistic children (Baron-Cohen et al., 1985). Other tests had fewer participants, including one set of belief attribution tests with an autistic group of only 10 participants (Baron-Cohen, 1989).

Theory of mind tasks also lack both convergent and predictive validity. Many theory of mind tasks fail to correlate with each other on performance in both autistic and non-autistic populations. In fact, even tasks of the same type, such as different types of False Belief tasks, failed to correlate with each other (Duvall et al., 2011; Hughes, 1998). In many studies that did not explicitly measure theory of mind, such as observations of non-verbal behaviour, eye tracking, and behaviour during computer games, autistic people demonstrated understanding of people’s intentions, goals and desires (Gernsbacher & Yergeau, 2019). Thus, the ability to read and decode social information does not appear to be well measured by existing theory of mind tasks.

Despite various factors that contradict the original hypothesis that autistic individuals do not possess theory of mind, and that the social difficulties associated with autism stem from deficits in theory of mind, researchers have continued to develop new tests to try to support the original idea that autistic people lack theory of mind. However, theory of mind tests have continued to provide evidence that within both autistic and neurotypical groups, theory of mind ability varies. Therefore, alternate explanations are needed to move forward in discovering the underlying cause of social difficulties.

1.2 The Double Empathy Problem

The belief that autistic people lack theory of mind aligns with the view of autism as a *disorder* that results in cognitive, social, and emotional deficits. This view can be harmful because it perpetuates stigma about autistic people. For example, when surveyed about their views of autistic people, non-autistic participants demonstrated a denial of human uniqueness traits in autistic people (Cage et al., 2018). This indicates a view of autistic people as ‘child-like’ or incapable of restraint. Consequentially, neurotypical individuals are less willing to interact with autistic individuals (Sasson et al., 2019) and are more likely to attribute negative characteristics to autistic people (Lim et al., 2017). Negative

views of autism in society have led to mental health consequences for many autistic individuals (Mitchell et al. 2021; Camus et al. 2022).

Autistic individuals have advocated for a shift in the perspective with which we view autism. Advocates suggest that autism should be viewed using a social model, in which autistic characteristics are considered different rather than deficits. The social model attributes many of the challenges autistic people face as a misalignment between what neurotypical people expect a social interaction to be and how autistic individuals interact in social settings (Woods, 2017); autistic individuals are often forced to adapt to an environment that was not designed for them, while neurotypical individuals are not expected to make changes to accommodate autistic people. Distinct social communication patterns between these two groups may have started as innate differences, but over time are thought to diverge further due to environmental, perceptual, and social factors (Bolis et al., 2017). Thus, rather than being a ‘problem’ within the individual, challenges faced by autistic people may actually be a result of a society that does not accept them due to group differences in social norms (Woods, 2017).

Viewed through this model, autistic differences in socialization may arise from a misunderstanding on the part of both parties. Though the default view is that autistic people struggle with using and reading non-autistic social norms, it may be the case that non-autistic people struggle just as much to read and exhibit socially expected behaviours during interactions with autistic people. This is the main idea behind the Double Empathy Problem Hypothesis, first introduced by Milton (2012).

The Double Empathy problem describes autistic social difficulties as the result of autistic and non-autistic people having different “norms” within their respective groups.

Typically, we use empathy to interpret how people might be feeling or thinking about a situation. While these predictions may serve neurotypical people well when interacting with other neurotypical people, they are often incorrect when attempting to predict autistic thoughts and feelings (Heasman & Gillespie, 2018; Sasson et al., 2017). This results in the incorrect assumption that autistic people are the reason that an interaction feels awkward, and that this is something that the autistic person is responsible for

correcting. The view of autism as a deficit has led to the dismissal of autistic experiences, a lack of autistic perspectives in research, and interventions that try to change autistic behaviour to better fit in. Autistic individuals often feel like they are responsible for bridging the communication gap with neurotypical individuals, resulting in exhausting and frustrating interactions (Crompton et al., 2020). Constant feelings of being misunderstood and having to expend considerable effort when socializing with neurotypical people lead to mental health consequences such as burnout or depression for many autistic people (Camus et al., 2022).

Logically, the bias held by neurotypical society goes against previous notions of what social interaction is, as it fails to see interaction as a product of both actors' experiences. Taking autistic perspectives into account also challenges the preconceived notion that the inability to read social subtext is a characteristic of autism. In fact, non-autistic people frequently misjudge the mental states of autistic people (Lim et al., 2022; Edey et al., 2016). The use of typical non-autistic social strategies in an interaction can feel imposing, invasive, or just inaccurate to autistic interaction partners. However, statements by autistic people that their neurotypical interaction partner's assumptions are wrong have often been ignored.

1.3 Social and Emotional Evidence for Double Empathy

The Double Empathy Problem hypothesis aligns with findings that non-autistic people often fail to pass theory of mind tasks when asked to predict mental states of autistic people. The Animated Triangles task (Abell et al., 2000) requires participants to attribute mental states to animated triangle "characters". When the characters were programmed to move in ways consistent with autistic actors, typically developing individuals failed to correctly identify the characters' feelings (Edey et al., 2016).

While autistic social communication styles may be different, this does not mean that they are less effective than neurotypical communication strategies. Autistic reactions to events have been rated by neurotypical individuals as different, but not less expressive (Sheppard et al., 2016). Differences in expression during communication may be more recognizable by others of the same neurotype, leading to better communication between

matched-neurotype pairs. Information transfer was found to be more effective in groups where all participants had the same neurotype than for mixed groups (Crompton et al., 2020). Autistic-autistic pairs also had unique patterns of creating mutual understanding (intersubjectivity) during their interactions (Heasman & Gillespie, 2019). While these patterns differed from those seen in neurotypical interactions, pairs were still able to effectively connect with one another.

Ease of communication may contribute to autistic preferences when it comes to socialization. Autistic individuals have reported feeling more comfortable in the presence of other autistic people than they do when with non-autistic people. In a group of school-aged children, autistic children were more likely to interact with peers who were also autistic (Chen et al., 2021). The types of interactions were also determined by the match or mismatch of neurotype, as same-neurotype interactions were more likely to be reciprocal and conversations were more likely to be about their thoughts and experiences. Autistic adults also appear to experience better social outcomes when interacting with other autistic people. In focus groups and interviews, autistic people reported feeling better understood, less stressed, and more comfortable socializing with other autistic people (Camus et al., 2022). Around other autistic people, they felt like they did not have to mask and could just be themselves (Crompton et al., 2020). Pairs of friends with higher similarities in autistic traits also had higher perceived friendship quality and reported greater levels of closeness, acceptance, and help, in addition to having longer friendships on average (Bolis et al., 2021). Successful autistic-autistic interactions and shared understanding during conversations support the double empathy problem.

1.4 Neurological Underpinnings of Double Empathy

Despite evidence supporting the double empathy problem in social and emotional contexts, there has been little investigation into the double empathy problem on a neurological level. Examining the basis of double empathy in the brain can aid in our understanding of autistic social differences. The field of social neuroscience has previously relied on single-participant paradigms to investigate interaction. Single-participant paradigms have measured responses to social stimuli such as pictures, video clips, and even live virtual interactions (Schurz et al., 2014; Schilbach et al., 2006; Bolis

& Schilbach, 2018; Sperduti et al., 2014; Ciaramidaro et al., 2014). These studies have provided important knowledge about the brain areas involved in processing and responding to social information, collectively known as the theory of mind brain network (Frith & Frith, 2006). The theory of mind brain network includes the medial prefrontal cortex (mPFC), posterior superior temporal sulcus (pSTS), anterior temporal cortex (ATC) and temporoparietal junction (TPJ). The theory of mind network is active when observing and responding to social interactions. Specifically, the TPJ is responsible for attributing and reasoning about mental states (Saxe & Kanwisher, 2003). The PFC is responsible for general aspects of social cognition, including detecting and tracking people, in addition to consideration of the other person and prediction based on trait attribution (Hartwright et al., 2014; Krause et al., 2012). The pSTS is involved in gaze tracking (Otsuka et al., 2019; Yang et al., 2015). The mentalizing network in autistic brains differs in both structure and function (Kana et al., 2012; McPartland et al., 2011). Differences in brain function are also present at the group level. Group level comparisons show that non-autistic brains have synchronous brain activity in the mentalizing network when watching movie clips that encourage theory of mind usage. Autistic brains had lower group level brain synchrony in the mentalizing network when watching the same movie clips (Lyons et al., 2019). This indicates that autistic brains may process social stimuli differently.

However, the brain's response to social stimuli may be fundamentally different from its response during real-time reciprocal social interactions. It is important to study the brain during naturalistic social interactions to obtain information that may not be captured when using isolated social stimuli. The study of the brain during social interactions (as opposed to observing social stimuli) is known as second-person neuroscience (Redcay & Schilbach, 2019).

Even using a second-person neuroscience approach, studying one person may not provide enough information to get an accurate understanding of what goes on during an interaction.

An interaction between two individuals is dependent on the experiences, perceptions, and reactions of both partners. Studying the brains of two individuals while they interact with each other provides a way to examine interactions from the perspectives of all parties involved, a method known as a dual-brain approach (Redcay & Schilbach, 2019). A dual-brain approach is especially important to utilize when studying autistic interactions, as autistic-neurotypical interactions have largely been studied from the perspective of the neurotypical individual without taking the autistic person's perspective into account. Additionally, further investigation of autistic-autistic social interaction is needed.

The simultaneous imaging of multiple brains is known as hyperscanning (Montague et al., 2002). Hyperscanning paradigms have revealed inter-brain synchrony between interacting partners in the theory of mind brain network during various activities including cooperative games (Jiang et al., 2015; Byrge et al., 2015), answering questions (Delaherche et al., 2015; Ahn et al., 2018), speaking and listening tasks (Descorbeth et al., 2020; Pinti et al., 2021), singing (Osaka et al., 2015) and playing instruments (Gugnowska et al., 2022). However, the amount of inter-brain synchrony between interacting partners can vary. Partner relationships and characteristics appear to affect synchrony. For example, romantic partners had higher synchrony than both friends and strangers (Pan et al., 2017). Partners who are closer in socioeconomic status also have higher synchrony with each other (Descorbeth et al., 2020). Synchrony also appears to be linked to interaction outcomes. When completing a cooperative task, increased synchrony in the right superior frontal cortex was associated with better cooperation performance (Cui et al., 2012; Pan et al., 2017). Higher synchrony is also associated with more enjoyable interactions and higher behavioural reciprocity (Nguyen et al., 2020). Given that autistic-autistic pairs usually have greater mutual understanding and shared traits, we would predict high inter-brain synchrony in these pairs.

Few hyperscanning studies have investigated the role of autism in partner synchrony. One recent study found that while neurotypical-neurotypical pairs had high synchrony in theory of mind areas during a conversation task, neurotypical-autistic pairs did not (Quinones-Camacho et al., 2021). This study did have several limitations. First, the

experimenter was present as part of all pairs. Though this did provide a way to control for what happened in the interaction and to examine the relationship between synchrony and autistic traits, it meant that the interaction was less naturalistic. This also may have resulted in some bias, since the researcher had participated in the experiment many times previously. Additionally, the experimenter knew what to expect while the new partner did not. While this may not have made much of a difference for some of the neurotypical participants, it could have created a greater difference between the partners' mental states in the autistic population since a common trait of autism is difficulty with new or unknown situations. Additionally, autistic-autistic interactions have not been measured using hyperscanning. Thus, the lack of inter-brain synchrony within neurotypical-autistic dyads may have been a result of the mismatch in communication styles.

The present study explores inter-brain synchrony as it relates to autistic traits. We used functional near-infrared spectroscopy (fNIRS) hyperscanning to measure brain activity in the mentalizing network during real-time unstructured social interactions. This method is less affected by head movement produced during conversation and allows participants to interact in a naturalistic environment. We also included story listening conditions with and without theory of mind elements to compare the inter-brain synchrony of partners with varying autistic traits during these conditions. We expected that those with low traits would have high synchrony when paired with other low-trait individuals, but low synchrony when paired with high-trait individuals. We also added a novel high-high trait group. In line with previous trait pair findings, we predicted that high-high pairs would have synchrony levels similar to the low-low trait group. This would support the expectations of the Double Empathy Problem.

Chapter 2

2 Methods

2.1 Participants

Participants were recruited from Western University. Participants were required to be fluent in English, have normal or corrected to normal vision and hearing, and to not have an autism diagnosis. One participant was excluded from the experiment due to a diagnosis of Tourette syndrome. Initially, 175 participants were recruited and completed an online questionnaire. Participants were invited to complete the next phase of the study, real-time interaction with a partner during fNIRS imaging, if their Autism-spectrum Quotient score was below 107 or above 117 (see materials section for rationale). In total, 90 individuals (45 pairs) completed this phase of the experiment. Three pairs were excluded from the final analysis due to poor signal quality. In total, 42 pairs ($n_{LL} = 12$, $n_{LH} = 16$, $n_{HH} = 14$; see below for a description of the groups) were included in the final analysis. Participants ranged in age from 17 to 35 ($M = 21.5$, $SD = 4.23$). The majority of participants identified as women ($N = 58$), with 23 participants identifying as men and 3 participants identifying as non-binary. Participants were predominantly white (46.4%), but also identified as South Asian (14.3%), Chinese (14.3%), Latin American (6%), Arab (4.8%), Black (2.4%), Filipino (1.2%), Korean (1.2%), West Asian (1.2%), and mixed race (8.4%).

2.2 Materials

2.2.1 Autism-spectrum Quotient

The Autism-spectrum Quotient (AQ) is a 50-item questionnaire that measures the presence and expression of autistic traits (Baron-Cohen et al., 2001; Appendix A). We

used the likert method of scoring this measure, as this method has higher internal consistency and test-retest reliability than the original binary scoring method (Stevenson & Hart, 2017; $\alpha = .79$). Items are scored on a scale of 1 to 4, with possible scores ranging from 50-200. Cut-offs for “high” and “low” autistic traits were determined using statistics from a previously collected sample of university students ($N = 1793$; See Figure 1). That is, categories of “low” and “high” autistic traits were determined by finding tertiles (i.e., values greater than $1/3$ and $2/3$ of the data) within the distribution of AQ scores from this sample. Scores of 106 or below were classified as “low” and scores of 117 or above were classified as “high”. Participants that scored between these values were not included in the study. Participant scores were used to create “low-low”, “low-high” and “high-high” pairings. Pairs were created based on participant availability.

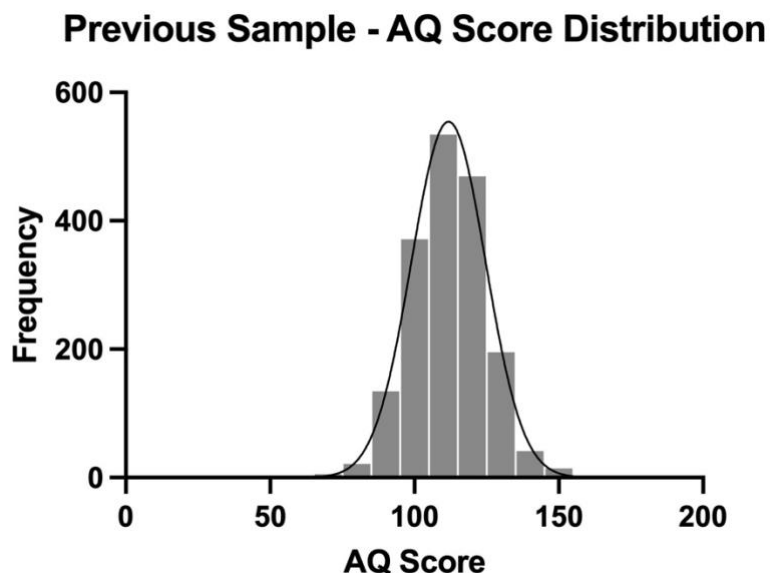


Figure 1. Distribution of Autism-spectrum Quotient scores from a previously collected sample of university students. Tertiles were calculated to determine cut-offs for “high” and “low” autism trait categories to be used in the current study.

Figure 2. Distribution of Autism-spectrum Quotient scores from a previously collected sample of university students. Tertiles were

2.2.2 Interaction Success Measure

For each conversation condition, participants were asked to rate the interaction on 6 dimensions (Alkire et al., 2022; see Appendix B; $\alpha = .85$). Participants responded to each item on a 5-point Likert-type scale, where 1 = not at all and 5 = the most. Participants were also asked which of the two conversations they enjoyed more and whether they liked their preferred interaction “a little more” or “a lot more”.

2.2.3 Stories

Dyads were presented with two stories. The first, which we called the theory of mind, or “ToM” story (Appendix C), was originally written by Johnson (2012) and designed to induce feelings of compassion and model prosocial behaviour. This story is about a young boy who is experiencing problems at home. The second, non-theory of mind, or “non-ToM” story (Appendix D), called Space Travellers, was a nonfiction passage about space rocks from a Nelson Literacy textbook (Mackenzie, 2007). Stories were designated by the researchers as “ToM” and “non-ToM” based on content; it should be noted that their ability to elicit theory of mind was not tested neurologically. Both stories were written at approximately a 6th grade level, and were about the same length. Story order was counter balanced.

2.2.4 Discussion Prompts

A list of discussion prompts was created for each story to be used if participants had difficulty sustaining a conversation for 5 minutes (Appendix E). If required, the researcher chose a prompt from a predefined list. Multiple prompts could be used throughout the interaction if needed. The researcher used their discretion to decide which prompt was best to use based on the interaction – for example, if a pair had already

discussed a topic on the prompt list, the experimenter would not choose that prompt.

Most participants did not require prompts, but those that did usually used between 1 and 2 prompts per conversation. Prior to the experiment, participants were encouraged to try their best to make conversation on their own. Participants were only prompted when it was clear they were struggling (i.e., after a couple seconds of silence) or if they requested a prompt.

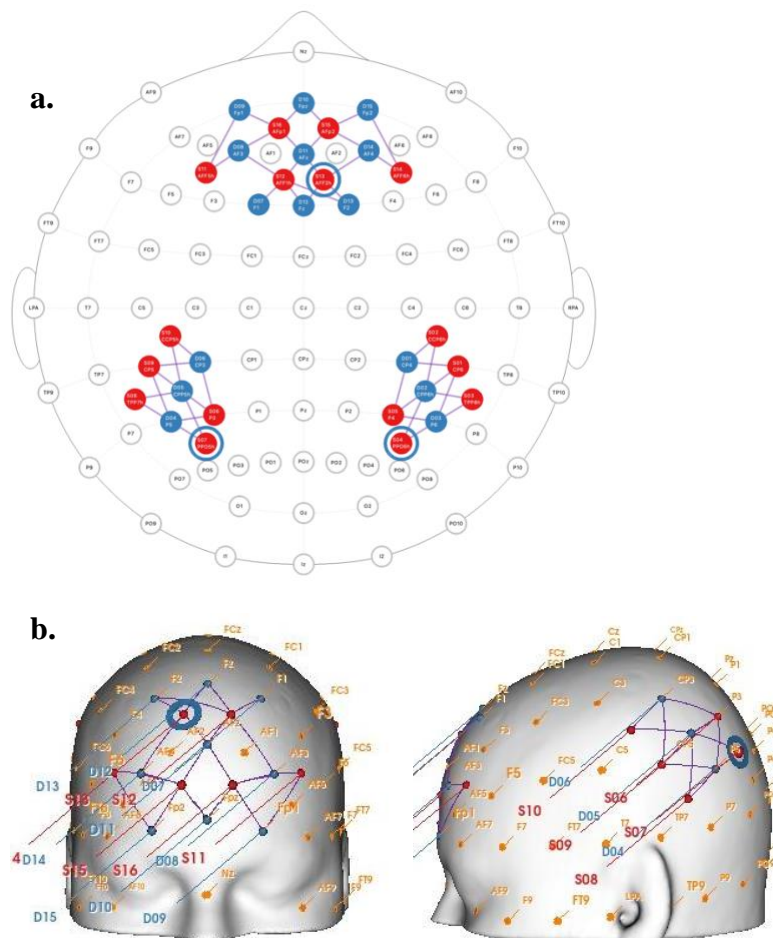


Figure 4. 2D (figure 2a) and 3D (figure 2b) depictions of the fNIRS optode montage with 48 channels total (3 short channels). Red circles represent sources and blue circles represent detectors. Purple lines represent channels. The average channel distance was 3 cm. Blue rings around sources represent the 3 short channels.

Figure 5. 2D (figure 2a) and 3D (figure 2b) depictions of the fNIRS optode montage with 48 channels total (3 short channels). Red circles represent sources and blue circles represent detectors. Purple lines represent channels. The average channel distance was 3 cm. Blue rings around sources represent the 3 short channels.

2.2.5 Imaging

A NIRScout system was used to measure brain activity using a continuous-wave (NIRx Medical Technologies LLC, Glen Head, NY). Dyads were connected to one machine. Light was emitted at 785, 808, 830 and 850 nm (although only light emitted at 785 and 850 nm were used in the final analysis) from 32 LED light sources and measured from 32 photodiode light detectors, to create a total of 96 channels. Optodes were split between participants, resulting in a 32-optode montage and 45 channels (plus 3 short distance) for each participant (see Figure 2). The average distance between sources and detector was 3 cm on a flexible fNIRS head cap. The location of the desired brain regions was first estimated using MNI coordinates (Evans et al., 1993; Descorbeth et al., 2020). The 10–20 international coordinate system was used to position the fNIRS cap and optodes for all participants. Sources were positioned at AFp1/AFp2, AFF1h/AFF2h, and AFF5h/AFF6h and over and CCP5h/CCP6h, CP5/CP6, P3/P4, PPO5h/PPO6h, TPP7h/TPP8h to create

channels that recorded activity over the prefrontal cortex (PFC) and bilateral temporoparietal junction (TPJ). Data was collected at a sampling rate of 3.9 Hz.

2.3 Experimental Procedure

Upon entering the lab, participants were measured and fitted with an fNIRS cap and Tobii eye tracking glasses. Eye tracking data was not analyzed in this report. Instructions were given prior to the start of the experiment. Participants were told that they were to view two videos, and that after each video they should discuss the video with each other. Participants were told to let the conversation flow naturally, even if the topic strayed from the video. They were asked to try their best to come up with things to talk about on their own, but were informed that the experimenter would give prompts to help out if needed.

Participants watched the first video, then discussed the contents of the video. Prompts were given if participants struggled to make conversation. After about 5 minutes of conversation, the experimenter stopped the participants from interacting and played the second video. Participants then talked about the second video for about 5 minutes.

2.4 fNIRS Analysis

Preprocessing and statistical analysis of the fNIRS signal were conducted in the NIRS BrainAnalyzeIR toolbox (Santosa et al., 2018). Prior to analysis, signals recorded at 808 nm and 830 nm were removed from each participant's data. Only signals recorded at 785 nm and 850 nm were analyzed because the toolbox functions used were only capable of analyzing two wavelengths. We chose the two wavelengths farthest away from each other to maximize signal to noise ratio. Additionally, 785 nm and 850 nm are the standard

wavelengths when data with only 2 wavelengths is collected. First, motion artifacts and low frequency scaling coefficients were removed using a wavelet filter with an interquartile range of 1.3. The fNIRS raw intensity signals were then converted to changes in optical density. After this, signals recorded from short channels were used as a regressor for physiological noise such as heart rate. Then, signals were converted to oxygenated hemoglobin concentration using the modified Beer–Lambert law (Baker et al., 2014).

We identified significantly correlated channels ($\alpha = .005$) using first-level inter-brain functional connectivity. Autoregression was used to account for correlations between adjacent time points. An FDR-corrected mixed effects model ($q < .05$) was used to identify significantly correlated channels at the group level. Between-group and within-group differences in synchrony were assessed using t -contrasts. Between group differences were examined for each of the four conditions individually, using “LL-LH”, “LL-HH”, and “HH-LH” t -contrasts. Within each group, t -contrasts were used to examine whether inter-brain synchrony was significantly greater than zero for each of the four conditions. Within-group differences between conditions were assessed using “ToM Story-NonToM Story” and “ToM Convo-Non-ToM Convo” t -contrasts.

Chapter 3

3 Results

3.1 Autism-spectrum Quotient Scores

Average ‘Low’ and ‘High’ Autism-spectrum Quotient (AQ) Scores are shown in Table 1.

We calculated the absolute values for differences in partner AQ scores and compared partner differences across groups to verify that Low-High pairs differed more in their AQ scores. The average difference in partner scores did not significantly differ for Low-Low ($M = 11.5$, $SD = 7.9$) and High-High ($M = 12.9$, $SD = 8.8$) pairs ($t(23.9) = 0.44$, $p = .667$, $d = 0.17$); Low-High ($M = 36.2$, $SD = 18.2$) partner score differences were significantly greater than differences for both Low-Low ($t(21.6) = 4.9$, $p < .001$, $d = 1.76$) and High-High pairs ($t(22.3) = -4.54$, $p < .001$, $d = -1.63$).

Table 1: Descriptive Statistics for AQ Scores

Group	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max
Low (AQ < 107)	40	95.3	8.6	73	106
High (AQ > 116)	44	134	14	117	164

3.2 Between-Group Contrasts

We aimed to determine whether Low-Low, High-High, and Low-High groups differed in pair inter-brain synchrony during story listening and conversation conditions with and without ToM elements. We used *t*-contrasts to compare group averages for inter-brain synchrony in channels across the mentalizing network between groups ($\alpha = .005$).

Between group comparisons were conducted for each of the four conditions. All contrasts used FDR-corrected p-values ($q < .05$).

3.2.1 Conversation

During conversations following the ToM story, we found significantly greater synchrony in Low-High pairs than High-High pairs in 8 channels across the mentalizing network (Figure 3a). These included 4 right TPJ-TPJ connections, 2 PFC-PFC connections, and 2 left TPJ-PFC connections. Comparing High-High and Low-Low pairs, we found greater synchrony for High-High pairs in 5 channels, and greater synchrony for Low-Low pairs in 5 channels. Both pair types had channels in PFC and bilateral TPJ. We found significantly greater synchrony for Low-High pairs than Low-Low pairs in one right TPJ channel and 4 channels across left TPJ and PFC; Low-Low pairs had greater synchrony than Low-High pairs in 3 channels across left TPJ and PFC.

During non-ToM conversations, we found significantly greater synchrony for Low-High than High-High pairs in 7 bilateral TPJ-PFC channels across the mentalizing network (Figure 3b). We found significantly greater synchrony for Low-Low pairs than High-High pairs in 10 bilateral TPJ-PFC channels and 1 PFC-PFC channel, while greater synchrony was found for High-High pairs than Low-Low pairs in 2 PFC-PFC channels and 1 left TPJ-TPJ channel. When comparing Low-Low pairs and Low-High pairs, we found greater synchrony for Low-Low pairs in 1 right and 1 left TPJ-TPJ channel, 1 PFC-PFC channel, and 2 left TPJ-PFC channels; we found greater synchrony in Low-High pairs in 2 PFC-PFC channels.

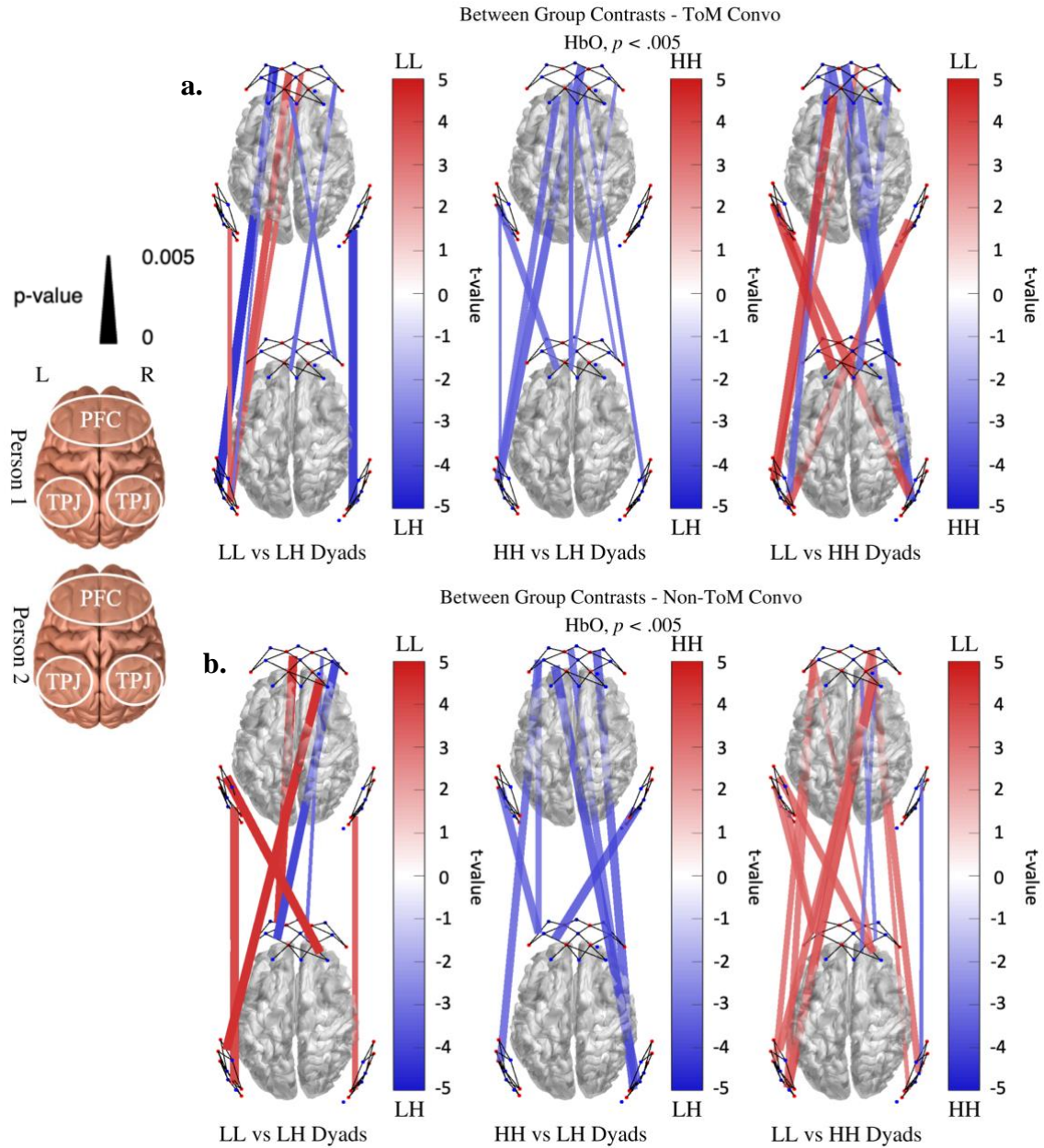


Figure 7. Between-Group for partner inter-brain synchrony in Low-Low, Low-High, and High-High dyads during conversation. Panel a shows group differences in synchrony during the ToM conversation and panel b shows group differences in synchrony during the Non-ToM conversation. Lines connecting brains represent channels where synchrony significantly differed ($p < .005$) between groups. Line colour indicates t-value and line thickness indicates p-value. For each contrast, positive t-values indicate greater synchrony in the group labelled at the top of the colour bar. Negative t-values indicate greater synchrony in the group labelled at the bottom of the colour bar.

3.2.2 Story Listening

During ToM story listening, we found significantly greater synchrony for Low-High pairs than Low-Low pairs in 9 channels across the ToM network (Figure 4a). These consisted of bilateral TPJ-TPJ connections and bilateral TPJ-PFC connections. Low-Low pairs only had significantly greater synchrony than Low-High pairs in one PFC-PFC channel.

Similarly, we found greater synchrony for High-High pairs than Low-Low pairs in 11 channels across the ToM network. We found only one right TPJ-PFC channel where Low-Low pairs had greater synchrony than High-High pairs. We did not find any significant differences in synchrony between Low-High and High-High pairs during ToM story listening.

During non-ToM story listening, we found significantly greater synchrony for Low-Low pairs than Low-High pairs in 6 channels; 4 of these were TPJ-TPJ connections, while 2 were right TPJ-PFC connections. We did not find greater synchrony for Low-High than Low-Low pairs in any of the ToM network channels (Figure 4b). Low-Low pairs had few differences in synchrony when compared to High-High pairs; in 2 TPJ-TPJ channels, we found greater synchrony for Low-Low pairs than High-High pairs, while we found greater synchrony for High-High pairs than Low-High pairs in 1 PFC-TPJ channel.

Comparing High-High and Low-High groups, we found that 6 TPJ-TPJ connections and 2 TPJ-PFC connections had greater synchrony in the High-High pairs. However, Low-High pairs had greater synchrony than High-High pairs in 2 left TPJ-TPJ channels and 1 right TPJ-PFC channel. Ranges for p and t values for all between-group comparisons can be found in Table 2; a summary of all comparisons can be found in Table 3.

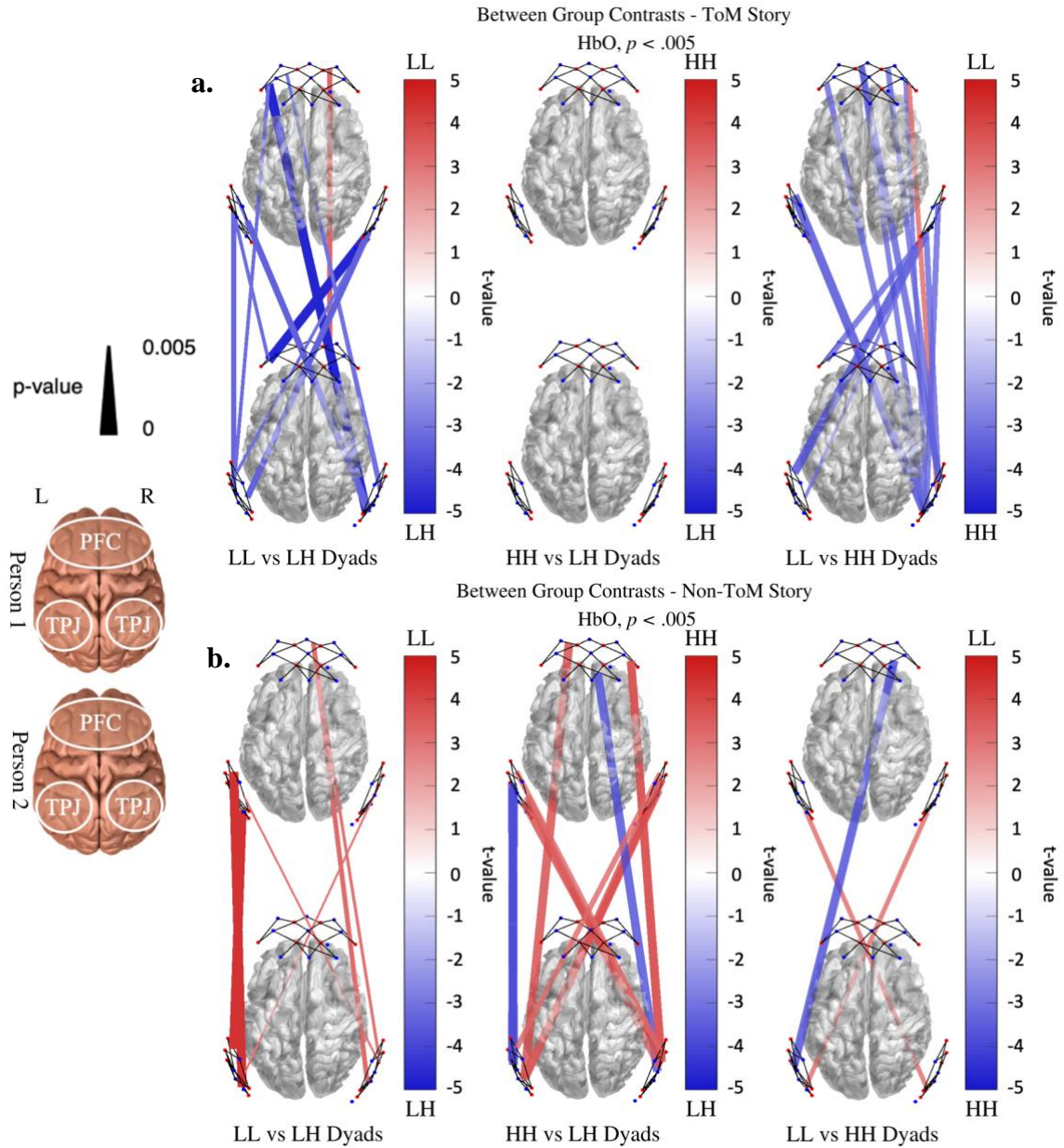


Figure 10. Between-Group for partner inter-brain synchrony in Low-Low, Low-High, and High-High dyads during story listening. Panel a shows group differences in synchrony during the ToM story and panel b shows group differences in synchrony during the Non-ToM story. Lines connecting brains represent channels where synchrony significantly differed ($p < .005$) between groups. Line colour indicates t-value and line thickness indicates p-value. For each contrast, positive t-values indicate greater synchrony in the group labelled at the top of the colour bar. Negative t-values indicate greater synchrony in the group labelled at the bottom of the colour bar.

Figure 11. Between-Group for partner inter-brain synchrony in Low-Low, Low-High, and High-High

Table 2: Range of t and p values for between-group comparisons

Comparison	Range	
	t	p
ToM Conversation		
LL vs LH	-6.24-5.37	.0000-.0049
HH vs LH	-5.19-4.91	.0000-.0049
LL vs HH	-4.43-4.58	.0001-.0049
Non-ToM Conversation		
LL vs LH	-4.79-5.31	.0000-.0049
HH vs LH	-4.09-3.85	.0003-.0048
LL vs HH	-4.82-4.89	.0001-.0049
ToM Story		
LL vs LH	-5.43-4.91	.0001-.0048
HH vs LH	-4.05-4.63	.0001-.0049
LL vs HH	-4.72-4.50	.0000-.005
Non-ToM Story		
LL vs LH	-5.03-5.23	.0000-.0048
HH vs LH	-4.55-4.01	.0001-.0047
L;L vs HH	-4.28-4.58	.0000-.005

Table 3: Summary of Between Group Comparisons

Comparison	# of channels with greater synchrony		
	LL	LH	HH
ToM Conversation			
LL vs LH	3	5	-
HH vs LH	-	8	0
LL vs HH	5	-	5
Non-ToM Conversation			
LL vs LH	5	2	-
HH vs LH	-	7	0
LL vs HH	10	-	3
ToM Story			
LL vs LH	1	9	-
HH vs LH	-	0	0
LL vs HH	1	-	11
Non-ToM Story			
LL vs LH	0	6	-
HH vs LH	-	3	8
LL vs HH	2	-	1

3.3 Within-Group Synchrony

We also conducted analyses to determine whether significant inter-brain synchrony was present within each group. We first used *t*-contrasts to compare group averages for inter-brain synchrony between all possible channel pairs against zero. This was done separately for each of the four conditions. Significant positive correlations are considered to represent inter-brain synchrony. Negative correlations were also present, but the meaning of these is unknown. Thus, in this results section we focused mainly on reporting inter-brain synchrony findings. Then, we used *t*-contrasts to compare inter-brain synchrony between conditions for each group ($\alpha = .005$). All contrasts used FDR-corrected p-values ($q < .05$).

3.3.1 Conversation

During conversations following the ToM story (Figure 5a), we found significant bilateral TPJ-TPJ synchrony and limited but significant left TPJ-PFC synchrony (only one channel) in Low-Low pairs. In Low-High pairs, we found significant neural synchrony in all the ToM brain areas except for right TPJ. In High-High pairs, we found significant PFC-PFC synchrony only; we did not find significant synchrony in right or left TPJ.

During conversations following the Non-ToM story (Figure 5b), we found limited but significant left TPJ-TPJ and left TPJ-PFC synchrony (one channel in each area), as well as significant PFC-PFC synchrony for Low-Low pairs. In Low-High pairs, we found limited but significant left TPJ-TPJ synchrony (one channel). We did not find significant synchrony in any of the other ToM brain areas for Low-High pairs. In High-High pairs, we did not find significant inter-brain synchrony in any of the ToM brain areas.

Comparisons of inter-brain synchrony across conversation types were mixed in the Low-Low group. We found 5 channels with significantly greater synchrony during the ToM conversation. The majority of these channels were bilateral TPJ-PFC connections; only one left TPJ-TPJ connection showed greater synchrony during the ToM conversation. We also found 9 channels with significantly greater synchrony during the non-ToM conversation in Low-Low pairs. Most of these channels were bilateral TPJ-PFC and PFC-PFC connections; only one left TPJ-TPJ connection showed greater synchrony during the non-ToM conversation.

Conversely, in Low-High pairs, we found higher synchrony during the ToM conversation than during the non-ToM conversation across 12 channels in the theory of mind network. These included bilateral TPJ-TPJ connections, PFC-PFC connections, and left TPJ-PFC connections. We found no channels with greater synchrony during the non-ToM conversation in Low-High pairs.

For High-High pairs, we found greater synchrony during the ToM conversation than the non-ToM conversation in 5 channels. Specifically, synchrony was greater in PFC-PFC and left TPJ-PFC connections for the ToM conversation in High-High pairs. We found higher synchrony during the Non-ToM story in one right TPJ-PFC connection; there were no other synchrony differences in right TPJ for High-High pairs. Within-group synchrony differences are shown in Figure 5c.

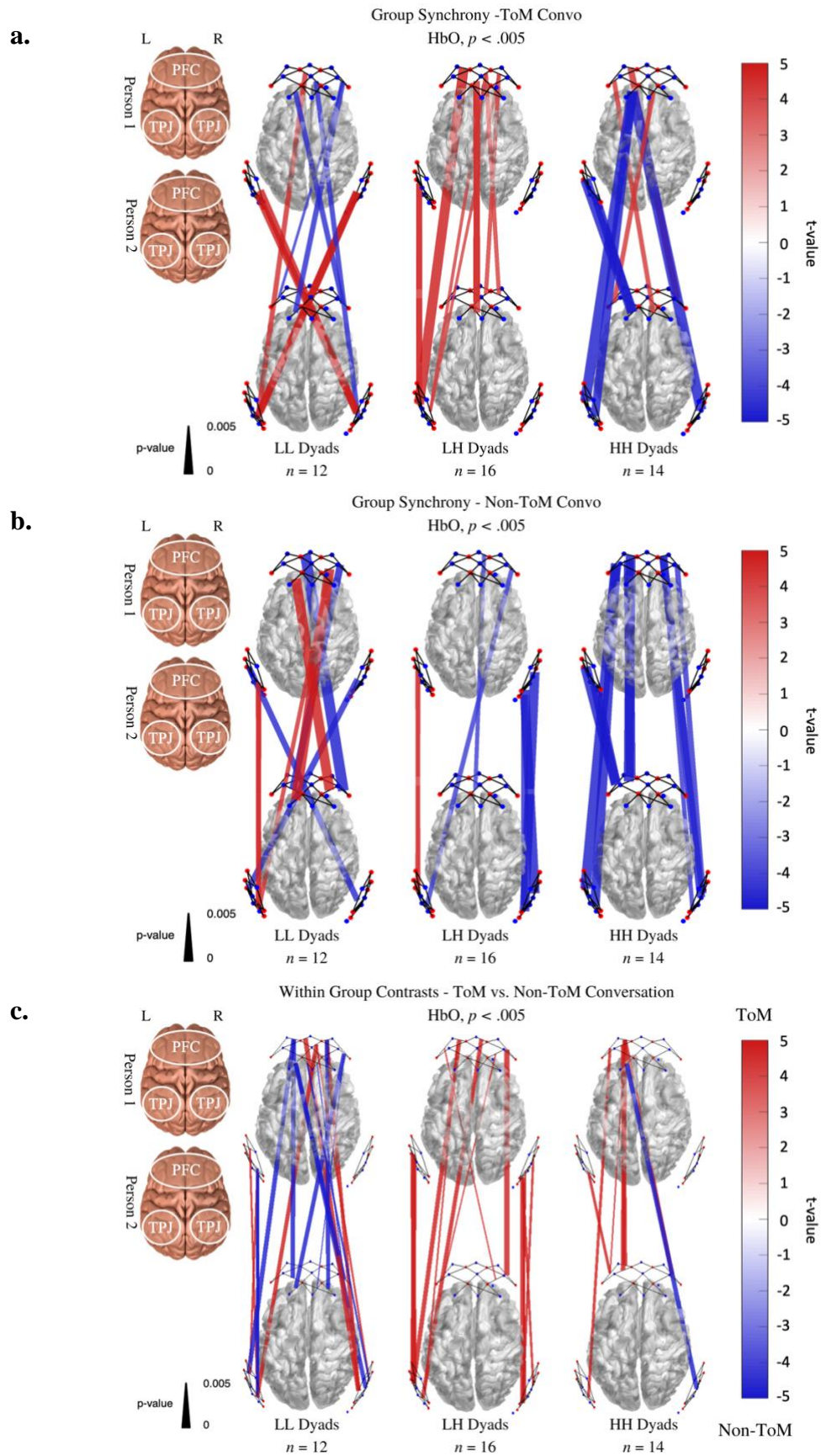


Figure 13. Within-group averages for partner inter-brain synchrony in Low-Low, Low-High, and High-High dyads during conversation. In panel a and b, lines connecting brains represent channels where synchrony was significantly different than zero for ToM (a) and Non-ToM (b) conversation conditions. Line colour indicates t-value and line thickness indicates p-value. Lines with positive t-values (correlations greater than zero) are considered to represent significant inter-brain synchrony. Panel c shows t-contrasts between the two conditions for each group. In panel c, lines connecting brains represent channels where synchrony significantly differed between ToM and Non-ToM conversation conditions. Line colour indicates t-value and line thickness indicates p-value. Positive t-values indicate greater synchrony during the ToM conversation and negative t-values indicate greater synchrony during the Non-ToM conversation.

3.3.2 Story Listening

During ToM story listening (Figure 6a), we did not find any significant inter-brain synchrony for Low-Low pairs in the ToM network channels. We did find significant neural synchrony for Low-High pairs between left TPJ and PFC. We also found significant neural synchrony for High-High pairs between right TPJ and PFC.

During Non-ToM story listening (Figure 6b), we found significant bilateral TPJ-TPJ synchrony as well as bilateral TPJ-PFC synchrony for Low-Low pairs. For Low-High pairs, we found significant synchrony in PFC, but not in right or left TPJ. In High-High pairs, we found significant bilateral TPJ-TPJ synchrony and bilateral TPJ-PFC synchrony.

Inter-brain synchrony was significantly greater during the non-ToM story than during the ToM story across the theory of mind network in 13 channels for Low-Low pairs. These included bilateral TPJ-TPJ channels, right TPJ-PFC channels, and PFC-PFC channels.

Inter-brain synchrony was significantly greater during the non-ToM story than during the ToM story in 8 channels for High-High pairs. These included bilateral TPJ-TPJ channels

and right TPJ-PFC channels. For Low-High pairs, synchrony was greater during the ToM story in 3 channels (1 left TPJ-TPJ channel and 2 right TPJ-PFC channels), and greater during the non-ToM story in 4 channels (2 right TPJ-PFC channels, 1 left TPJ-PFC channel, and 1 PFC-PFC channel). Within-group synchrony differences are shown in Figure 6c. Ranges for p and t values for all within-group comparisons can be found in Table 4; a summary of all within-group comparisons can be found in Table 5.

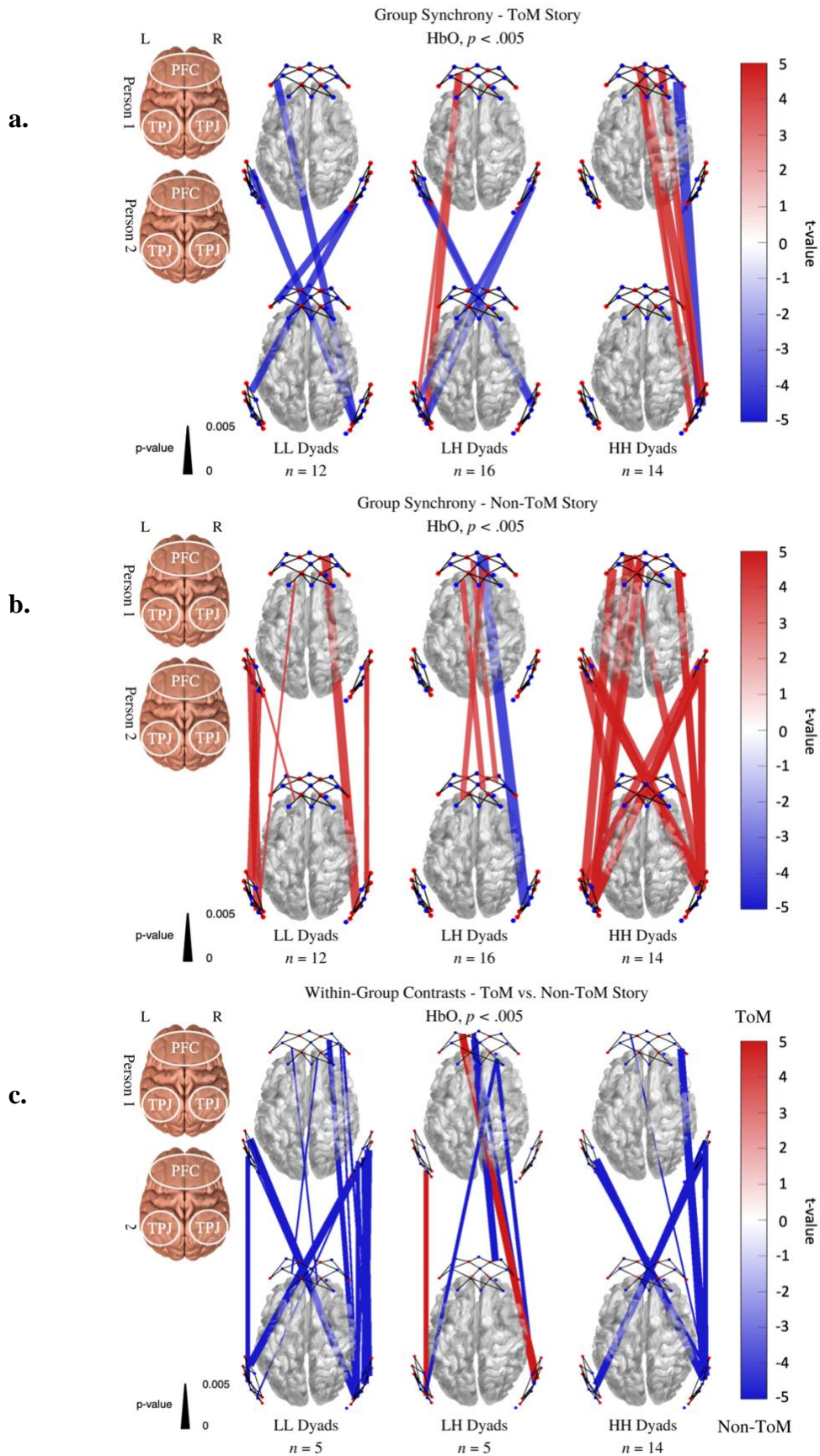


Figure 16. Within-group averages for partner inter-brain synchrony in Low-Low, Low-High, and High-High dyads during story listening. In panel a and b, lines connecting brains represent channels where synchrony was significantly different than zero for ToM (a) and Non-ToM (b) story conditions. Line colour indicates t-value and line thickness indicates p-value. Lines with positive t-values (correlations greater than zero) are considered to represent significant inter-brain synchrony. Panel c shows t-contrasts between the two conditions for each group. In panel c, lines connecting brains represent channels where synchrony significantly differed between ToM and Non-ToM story conditions. Line colour indicates t-value and line thickness indicates p-value. Positive t-values indicate greater synchrony during the ToM story and negative t-values indicate greater synchrony during the Non-ToM story.

Table 4: Range of t and p values for within-group comparisons

Pair Type	Range	
	t	p
ToM Conversation		
LL	-37.78-10.14	.0000-.005
LH	-64.45-12.33	.0000-.005
HH	-78.02-14.92	.0000-.005
Non-ToM Conversation		
LL	-37.76-9.43	.0000-.005
LH	-54.19-12.66	.0000-.005
HH	-63.13-17.44	.0000-.005
ToM Story		
LL	-47.06-14.73	.0000-.005
LH	-77.67-15.28	.0000-.005
HH	-59.99-14.24	.0000-.005
Non-ToM Story		
LL	-58.41-12.80	.0000-.0049
LH	-64.79-12.81	.0000-.005
HH	-63.39-16.61	.0000-.005

ToM vs. Non-ToM Conversation

LL	-7.68-6.07	.0000-.0049
LH	-4.35-4.00	.0001-.0048
HH	-5.20-4.87	.0000-.0048

ToM vs. Non-ToM Story

LL	-4.54-4.67	.0001-.0049
LH	-4.35-4.28	.0001-.005
HH	-4.63-4.68	.0001-.0049

Table 5: Summary of Within-Group Comparisons

Group	# of channels with greater synchrony		Synchrony > 0	
	ToM	Non-ToM	ToM	Non-ToM
Conversation				
LL	5	9	Yes	Yes
LH	12	0	Yes	Yes
HH	5	1	Yes	No
Story				
LL	0	13	Yes	No
LH	3	4	Yes	Yes
HH	0	8	Yes	Yes

3.4 Interaction Success

For each conversation condition, participants were asked to rate the interaction on 6 dimensions using a 5-point Likert-type scale, where 1 = not at all and 5 = the most. The 6 answers were summed to get a score for each participant for the ToM conversation and the Non-ToM conversation. We also calculated an overall interaction score by adding the two conversation scores together. Interaction success measures were only collected for part of the sample and included some pairs that were excluded from the final fNIRS analysis. In total, 42 individuals (21 pairs; $n_{LL} = 8$, $n_{LH} = 6$, $n_{HH} = 7$) were included in the analysis. We first examined overall interaction scores to see whether these differed between individuals with high and low autistic traits. At the individual level, those with low autistic traits ($n = 22$, $M = 50.8$, $SD = 8.2$) did not rate interactions with their partner differently than those with high autistic traits ($n = 20$, $M = 53.0$, $SD = 10.3$), ($t(40) = 0.77$, $p = 0.448$, $d = 0.24$).

We also conducted analyses based on pair type to see if participants within certain pairs rated each other differently. We conducted a two-way repeated measures ANOVA to examine the effect of conversation type and group on interaction scores. There was not a significant interaction between conversation type and group ($F(2, 39) = 0.81$, $p = .451$, $\eta^2 = .02$). Simple main effects analysis revealed no significant effect of conversation type on interaction scores ($F(1, 39) = 0.03$, $p = .865$, $\eta^2 = .00$). There was also no significant effect of group on interaction scores ($F(2, 39) = 1.07$, $p = .352$, $\eta^2 = .02$).

We also subtracted pair interaction success scores and compared the mean absolute values to determine whether any pair types had greater discrepancies in their scores. We conducted a two-way repeated measures ANOVA to examine the effect of conversation

type and group on interaction score differences. There was not a significant interaction between conversation type and group ($F(2, 18) = 3.19, p = .065, \eta^2 = .12$). Simple main effects analysis revealed no significant effect of conversation type on interaction score differences ($F(1, 18) = 3.54, p = .076, \eta^2 = .07$). There was also no significant effect of group on interaction score differences ($F(2, 18) = 1.16, p = .335, \eta^2 = .075$). Descriptive statistics for interaction success scores and score differences can be found in Table 6.

Table 6: Descriptive Statistics for Interaction Success Scores

Pair Type	<i>n</i>	ToM Score		Non-ToM Score	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Interaction Scores					
LL	16	26.1	7.0	24.3	7.2
LH	14	26.2	6.3	24.3	4.4
HH	12	26.0	6.0	28.8	10.3
Interaction Score Differences					
LL	8	4.1	2.1	3.6	1.7
LH	7	3.3	1.2	4.2	2.9
HH	6	3.4	4.0	7.3	3.6

Chapter 4

4 Discussion

The aim of the present study was to investigate neural synchrony as it relates to autistic traits of pairs during real-world, face-to-face social interactions. We wanted to examine neural synchrony between pairs with varying levels of autistic trait expression in conversation and story listening conditions with and without elements designed to elicit theory of mind (ToM) processing. We used hyperscanning to determine whether neural synchrony patterns during conversation and story listening align with the Double Empathy Problem hypothesis.

4.1 The Double Empathy Problem

Overall, the results did not align with our hypotheses. We expected that, in line with the Double Empathy Problem hypothesis, we would consistently find greater neural synchrony in Low-Low and High-High pairs than in Low-High pairs. According to this hypothesis, we would not have expected to find higher synchrony for Low-Low pairs when compared to High-High pairs. During both ToM and non-ToM conversation conditions, we found less synchrony overall for High-High pairs than for Low-High pairs. Similarly, we found less synchrony for High-High pairs than Low-Low pairs in many channels in the non-ToM conversation condition.

However, not all results were consistent with this pattern. When comparing Low-Low and High-High pairs during the ToM conversation condition, we did not find greater synchrony across the ToM network for either group; we found greater synchrony for

Low-Low pairs in some channels, while we found synchrony for High-High pairs in other channels. We also found higher synchrony overall during the ToM story for High-High pairs than for Low-Low pairs. Additionally, when comparing group synchrony against zero, we found that High-High pairs exhibited significant inter-brain synchrony in the ToM network during three of the four conditions. In fact, Low-Low pairs did not exhibit significant synchrony during the ToM story, while High-High pairs did.

Taken together, these results suggest that individuals with high autistic traits exhibit different patterns of inter-brain synchrony than those with low autistic traits. Though we did not find support for the Double Empathy Problem, we did find evidence that individuals with high autistic traits can synchronize with each other. High-high pairs appeared to synchronize to a greater degree during story listening conditions than in conversation conditions. This could be an indicator that those with high autistic traits have more difficulty utilizing the ToM network during conversation than during story listening. Alternatively, our results could mean that those with high autistic traits use different neural mechanisms during conversation than those with low traits.

One interesting finding was the occurrence of higher synchrony in one right TPJ-TPJ channel for High-High pairs when compared to Low-Low pairs. Although synchrony was greater for Low-Low pairs in many other channels in this comparison, this channel was the only TPJ-TPJ connection in which synchrony differences were present. Since most TPJ-TPJ connections did not have synchrony differences, group differences in TPJ usage during the Non-ToM Conversation appear to be minimal.

4.2 Low-High Pair Synchrony

Inter-brain synchrony in the Low-High trait group was greater than we expected across conditions. Low-High pairs were expected to have low or no significant inter-brain synchrony, specifically in the conversation conditions. Synchrony was expected to be significantly less when compared to the Low-Low group, which would have been in line with recent findings from Quinones-Camacho et al. (2021), who found greater synchrony for neurotypical-neurotypical pairs than autistic-neurotypical pairs and no significant synchrony in autistic-neurotypical pairings during conversation when compared to zero. We expected a mismatch in autistic traits to produce results similar to autistic-neurotypical pairings, since previous studies that used traits as a grouping variable produced similar results to those that separated groups by diagnosis (Bolis et al., 2021; Chen et al., 2021; Camus et al., 2022). Contrary to our expectations, we found that Low-High pairs only had less synchrony than Low-Low pairs overall in the non-ToM story condition. This is especially surprising, because participants were least likely to be utilizing ToM during this condition; we expected that Low-Low pairs would have high levels of synchrony in conditions that required them to use ToM to a greater degree. We also found significant synchrony in Low-High pairs in at least one channel in all four conditions when compared to zero. The most surprising condition was the non-ToM conversation condition, where we found that Low-High pairs had significant synchrony in many channels across the ToM network.

The ambiguity of some of our results, specifically in the Low-High group, suggests that partner inter-brain synchrony is complex and may be dependent on several factors other than autistic traits. Since the focus of the current study was to examine the relationship

between neural synchrony and expression of autistic traits, we did not control for other traits such as socioeconomic status, level of education, personal interests, or comorbid disorders such as ADHD. Inter-brain synchrony may be higher between pairs with shared traits that are not autism related. For example, those with similar socioeconomic background had higher synchrony with each other than pairs from different social classes (Descorbeth et al., 2020). It is possible that pairs within each group may have had high similarities in other areas, which could compensate for differences in social communication styles and allow them to relate to each other more.

4.3 Within-Group Findings – Story Conditions

An interesting finding in our results was that both the High-High and Low-Low groups exhibited higher synchrony in the mentalizing network during the non-ToM story condition than they did during the ToM story condition. One potential explanation for this result is that participants found the non-ToM story more engaging than the ToM story. Participants that enjoy learning about space, or that enjoy learning in general, may have preferred hearing facts about space more than a narrative. Additionally, the non-ToM story was 4 minutes in length while the ToM story was 8 minutes long. In fact, Dmochowski et al. (2012) have shown that neural synchrony increases the more engaged people are during story listening. Another possible explanation is that partners synchronized more during the non-ToM story because it contained educational content. In a classroom setting, students who showed greater neural synchrony with other students in brain areas including the prefrontal cortex during a lecture performed better on the final exam (Meshulam et al., 2021). Additionally, the anterior right TPJ may be involved in attentional processes as well as ToM processes (Krall et al., 2014). Thus, synchrony

during the non-ToM story could mean that participants were highly attentive and were learning during the non-ToM story.

4.4 Negative Correlations

A surprising pattern that emerged from our study is the predominance of negative correlations when comparing groups against zero. While various studies have examined the importance of negative correlations in neural communication, such as fMRI-based functional connectivity, much less is known about the importance of negative correlations in two-person neural coupling. In fact, it is unclear whether negative correlations have a similar function, and therefore can be interpreted similarly to positive correlations (Mohanty et al., 2020). In functional connectivity between brain regions, phase misalignment produces negative correlations, and a similar factor may be in play in our task (Zhan et al., 2017). Phase misalignment driving negative correlations during conversation could potentially be attributed to speaker-listener role switching. High-High pairs had a high incidence of anticorrelated channels in both conversation conditions. This suggests that High-High pairs may have a unique brain response during partner interactions that we do not yet understand. This would align with previous findings that autistic-autistic pairs had unique patterns of intersubjectivity during their interactions (Heasman & Gillespie, 2019).

4.5 Interaction Success Ratings

Since interaction rating scores were a late addition to our study, they were not obtained for the full sample. Due to small group sizes, the interaction rating score comparisons may be underpowered. Additionally, some of the pairs included in the interaction score

calculations were excluded from the final synchrony analyses. Thus, interaction rating scores are only meant to provide exploratory insights. Surprisingly, we did not find differences in conversation ratings between groups. We expected participants to prefer talking to partners who had similar trait levels, in line with previous findings that individuals are more comfortable in interactions with people who communicate in similar ways (Camus et al., 2022; Crompton et al., 2020). However, the results we found are consistent with Alkire et al.'s (2022) study, where autistic children were paired with either neurotypical or autistic partners and asked to rate a short unstructured interaction with their partner. There were no significant differences in interaction success ratings, regardless of partner type. We also examined differences in partner scores. Previously, associations have been found between interaction enjoyment and partner synchrony (Nguyen et al., 2020). The lack of group differences in partner interaction success score discrepancies may be related to the inconclusive results when comparing group synchrony during conversation.

4.6 Limitations and Future Directions

This study was the first of its kind to use fNIRS hyperscanning to examine neural synchrony in pairs where both partners had high autistic traits. The unique patterns observed within each group highlight the need for replication to see whether these patterns are consistent across pairs of the same type. If possible, larger sample sizes should be used to provide more power. The current study used autistic traits within a neurotypical population to investigate neural synchrony in matched and mismatched pairs. Future work should extend this to include diagnosed autistic individuals and examine whether similar patterns in interpersonal neural synchrony emerge.

There are several limitations to the current study that should be considered. First, our sample consisted mainly of university students from one community. Our population may have higher levels of education than the general population. Most university courses require students to practice having meaningful discussions with their peers, so university students may have heightened conversation skills. Our sample also consisted of mostly women. Autistic women are more likely to mask autistic social behaviours starting from a young age to fit in with neurotypical peers (Lai et al., 2016; Dean et al., 2017). Women with high autistic traits who do not have a diagnosis would likely have a similar experience. Participants with low autistic traits in the Low-High pairs may experience interactions similarly to interactions with a low trait individual as a result. High trait individuals in these pairs would have had lifelong practice interacting with low-trait individuals. It is possible that they have developed compensatory mechanisms in the brain that allow them to synchronize with low trait interaction partners in the same way that they would with other high trait individuals. It is also possible that other forms of neurodivergence that we did not control for, such as ADHD, impact partner interbrain synchrony. Future studies should explore the effect of other traits like comorbid diagnoses and gender on neurotypical and autistic neural synchrony. Studies should include a wider range of participants to be more representative of the general population.

Another consideration is that one of the symptoms of autism is difficulty adapting to new situations (5th ed.; DSM-5; American Psychiatric Association, 2013). Those with high autistic traits may take longer to feel comfortable with an interaction partner. High-High pairs might take longer to experience synchrony at the same level as Low-Low pairs.

Future analyses should examine synchrony as a function of time spent with a partner to investigate this possibility.

Another limitation is that we were unable to verify whether the stories we chose elicited ToM network activity. We chose stories that we thought were the most likely to produce the desired outcome based on their content. However, it is possible that participants could have been using theory of mind during the non-ToM story, or that they were not using theory of mind during the ToM story. Future studies could analyze participant responses to stories using fMRI and behavioural measures to choose the optimal stimuli for replication.

Synchrony may also be driven by conversation content. Interactions were unstructured, so each pair had unique conversations that varied in content. We plan to transcribe and examine conversation content in the future to see whether specific content is associated with interbrain synchrony between partners. The interactions we observed represent only a small fraction of an individual's daily social experiences. Future studies could also include a larger focus on conversation content and examine autistic-neurotypical synchrony across conversations in different contexts.

4.7 Conclusion

The present study examined partner inter-brain synchrony among pairs with varying levels of autistic traits. Contrary to our expectations, we did not find matched pairs to have consistently higher inter-brain synchrony during story listening or conversation. However, pairs of different types had unique patterns of neural synchrony that should be further examined with future research. We also compared interaction rating scores and

partner score differences between groups. We found no between-group differences in partner rating scores. This indicates that partner type did not affect the enjoyability of the interaction. This was the first study of its kind to include High-High trait pairs. Further investigation of neural synchrony as it relates to autism is needed, specifically with the inclusion of autistic-autistic interaction. Future studies should consider controlling for other variables such as comorbid diagnoses and gender.

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Appendices

Appendix A: Autism-spectrum Quotient

Scoring:

Items were scored on a likert scale from 1 = *definitely agree* to 4 = *definitely disagree*.

The following items were reverse scored (4 = *definitely agree* to 1 = *definitely disagree*):

2, 4, 5, 6, 7, 9, 12, 13, 16, 18, 19, 20, 21, 22, 23, 26, 33, 35, 39, 41, 42, 43, 45, and 46.

Instructions:

Many of these questions ask about your interactions with other people. Please think about the way you are with most people, rather than special relationships you may have with spouses or significant others, children, siblings, and parents. Everyone changes over time, which can make it hard to fill out questions about personality. Think about the way you have been the majority of your adult life. Please answer all questions, and please respond with your first instinct.

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree

10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree

28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree

47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

Appendix B: Interaction Success Questionnaire

Participants responded to each item on a 5-point Likert-type scale, where 1 = not at all and 5 = the most.

Presented twice, once for “Interaction 1” and once for “Interaction 2”:

Instructions: Think about the interaction you just had with the other participant and how you felt while talking to them throughout the experiment. On a scale from 1 to 5, please rate the following things:

- How much did you enjoy the interaction?
- How smooth/natural/relaxed was the interaction?
- How much would you like to interact with [partner] again?
- How pleasant was the interaction?
- How forced/strained/awkward was the interaction? [REVERSE CODED]
- How satisfying was the interaction?

Presented at the end of the questionnaire:

- Thinking about all of the things you rated for each interaction, which of the two interactions did you like better overall?

Appendix C: ToM Story

“See ya later, Eric,” Brandon, my best friend, said with a shrug.

“Yeah. Later,” I replied as my heart sank with bitter disappointment.

For the third time that week, my friends were all ditching me. The pool had just opened after Memorial Day, so each school day, at exactly 3:03, the guys got on their bikes and raced each other to the pool. The Johnston Community Pool had a new slide that was supposedly 20 feet tall with a “waterfall” at the end that drenched you right before shooting you out in to the deep end of the pool.

Brandon was the only one who even noticed that I couldn’t join in the guys’ bike ride all the way across town. Because I was bikeless, I couldn’t keep up with the guys as they road to the pool and I wasn’t allowed to walk that far by myself. I turned in the opposite direction from the pool and begrudgingly walked toward my house.

Last night’s argument between my parents rang in my ears as I kicked a rock down the road. My legs carried me back to the bickering even as my brain tried to reason an excuse to stay away for a few more hours. Each step brought back the stinging words my parents shouted at each other as they slammed their bedroom door. Yeah, I thought, like that will drown you out. Of course it had been about money, again. That was all anyone talked about in my house any more. Last night was no different.

“How can you possibly spend \$145 out with your friends when we supposedly can’t even afford to spend half that on Eric’s school supplies?” My mother had screamed from the other side of the bedroom door.

Please, I had silently pleaded, leave me out of this.

“That kid has way more than I ever had! And I need a night out every once in awhile to get away from you!” My father had retorted.

Reviewing the fight in my head caused my legs to turn to lead. My body and brain silently argued with each other about the necessity of actually going home right away. I slowed my pace until I stopped next to a giant rosebush about a block away from school.

“This sucks,” I murmured to myself as I lifted my backpack off my shoulder. With three good swings in the air, I aimed my backpack at the innocent bush. The crimson roses shook with fear under my mighty blows.

One more good whack and I managed to decapitate three rosebuds from the pack. The red swirls of petals stared up at me from the sidewalk demanding an explanation for their early deaths.

“Sorry,” I whispered.

“Eric Schmidt!” A voice from behind me boomed like a cannon.

“Busted,” I groaned hoping beyond hope that whoever was behind hadn’t seen the malicious attack on the poor unsuspecting rosebush just now.

Mr. Howard, my 7th grade Pre Algebra teacher at Johnston Middle School, was making his way down the street toward me. He was, by far, my favorite teacher at JMS. He knew how to make math fun. He wheeled his prized navy blue Trek 10 speed toward me. Mr. Howard was an avid bike enthusiast, and especially loved to cycle in the summer. He was quickly closing the gap between us on the sidewalk as he strode toward me. It’s weird to think about teachers having a life outside of school, but on Mr. Howard it seemed to fit that he would have such a cool hobby.

“Yes, sir?” I turned to face Mr. Howard, putting on my best angelic face.

“I don’t know that I’ve ever seen you without your entourage before,” he said with a slight turn of his head. He reminded me of my golden retriever, Daisy. She always cocked her head to one side whenever anyone uttered the word “food” in her presence.

“They’re all at the pool,” I mumbled.

“Ah. And I suppose that has something to do with why you’re attacking the neighborhood rose bushes?” Mr. Howard smiled at me, his eyes crinkling around the edges with light laugh lines.

“Sorry, sir. It just really sucks. My dad just lost his job because of budget cuts, and my old bike got stolen even though I locked it up every time I went anywhere. Now the guys all get to go to the pool every day after school, but I can’t. I have to go home and sit in my stupid house with - ” I trailed off, not wanting to get in to what would be waiting for me at home.

“Mr. Schmidt,” Mr. Howard gently interrupted me, “I understand. Losing a bike is like losing a dear friend. It’s freedom, absolute freedom to feel the speed of a great bike as you

race down the road. But look, I know things will get better. You just have to have faith. In fact, I promise you things will look better tomorrow. They always do.”

With that, he stuck out his hand.

“Sir?” I questioned.

“Let’s shake on it. Things will get better. If they don’t, you can blame it all on me.” Mr. Howard’s dark gray eyes echoed the sincerity in his voice. I stuck my hand out and grabbed Mr. Howard’s calloused hand. Even though he wore biking gloves when he rode, it was clear that these hands had spent many hours melded to his bike’s handlebars.

He gripped my hand like a vice, shook twice, and let go.

“Try not to kill any more flora on the way home,” he said with a hint of amusement in his voice.

“Yes, sir,” I grinned back at him.

The next day...

Brandon asked, “Dude, can’t you just, like, get a ride to the pool later?”

“Can’t. Dad’s out interviewing for a new job and Mom doesn’t get off work until 5. The pool’s practically closed by then. There’d be no point.”

I lied through my teeth, but there was no way I could tell Brandon the truth about what was waiting for me. I knew Dad would be sitting on the couch, half way through a six-pack by the time I got home.

My mother would always quip, “If you spent half your energy on finding a new job as you do on keeping Budweiser in business...”

“I’d be twice as miserable as I am now,” my dad would reply.

I watched Brandon swing his leg over the red mountain bike. Bitter resentment built up inside me like a slow fire burning.

“Well, I’ll text you when I get home. Later,” Brandon said he quickly pumped the pedal.

“Later,” I echoed to his back as he pedaled hard to catch up with the other guys. The gap between us grew and I felt myself put on the mask of indifference I wore every time I went home. To show frustration would be to show “ingratitude” according to my dad.

I turned my back on JMS and walked down the cracked sidewalk.

“Can’t wait to get home sweet home,” I sneered.

About three feet in front of me, a single daisy poked its way out of a particularly large split in the concrete. I was just about to stomp on it out of pure malice when I heard a voice behind me.

“I thought we had a deal, Mr. Schmidt.”

I sighed, “Look. I know you’re just trying to be nice and all, but I don’t see how a simple handshake is going to change anything.”

Mr. Howard walked toward me with his prize-winning racing bike. The gears made a click, click, click sound as the brand new tires gently bounced across the crevices in the

sidewalk. It looked like Mr. Howard had even waxed it. The sun sparkled on the body of the bike, and the spokes nearly blinded me in the early summer sunshine. An ache from deep inside my chest spread throughout my body as I looked at the beautiful bike before me.

“Well. That’s true. But, I can’t, in good conscience, give you this bike if I think you’re going to return to a life of crime,” Mr. Howard said with a gentle chuckle in his voice.

“W-What?” I stammered, “Give me?”

“I got to thinking about our conversation yesterday. I think you need this more than I do. A good bike knows where it’s needed, and quite frankly, this one knows you need it. It wouldn’t leave me alone last night. I’ll survive until I can save up enough to buy another one.” As he finished talking, he passed the handlebars to me. The rubber bumps on the handles scratched my hands, begging me to hop on and give them a test run.

“You... You’re serious?” I gaped. I tested the gears, changing the speed from 1 up to 10 and back again.

“Try it out,” he said as he gave me a gentle punch on the shoulder.

“I... I can’t just take...” I started.

“Yes,” Mr. Howard interrupted me, “you can. It’s yours. I won’t take no for an answer.”

“Thank you, sir,” I cried as I swung my right leg over the seat. The pedals pushed back with equal pressure against my feet. I had never even touched a bike like this before, let alone ridden one. The bike felt like an extension of my own legs, easily responding to my every request. Pedaling faster than I ever had before, I felt a weight lift itself off my shoulders. The tires beat out a steady rhythm on the cracked concrete as they adjusted to the cracks and crevices. It’s my bike, my bike, mybikemybikemybikemybike, I thought in time with the tha-thump of the tires. The wind whistled past my ears as I leaned forward over the handle bars. I felt just like Daisy when she stuck her head out of the car window. I knew I had the same goofy grin she gets on her face when her big, floppy ears blow in

the breeze. Then, with a weightlessness I hadn't felt for months, I leaned back on the seat and let go of the handles.

"THANK YOU!!" I shouted, fists raised high to the sky.

Appendix D: Non-Tom Story (Space Travellers)

They come from the depths of the solar system, strange visitors with amazing information about Earth's past. Are they aliens from another planet? No, they're comets, asteroids, and meteoroids. What are they and what can they tell us about our planet?

You might describe a comet as a huge, dirty snowball that orbits the Sun. Most comets have a nucleus, or centre, that's made of ice and dust. The most striking feature of a comet is its tail. As a comet zooms closer to the Sun, its frozen surface begins to turn into gas. Gas and dust stream out into a tail that can stretch as far as 10 million km. When the comet is far away from the Sun, the comet's tail disappears. Asteroids are made of rock, but they may also contain metal. Some asteroids are shaped like balls, but often these space rocks are shaped like lumpy slabs or bricks. Some meteoroids are chunks of asteroids, while others may come from old comets. As meteoroids fall through Earth's atmosphere, they heat up and begin to glow. We call these glowing pieces meteors. But if one happens to hit our planet's surface, it gets a new name: meteorite.

Where do these space rocks come from? Comets mostly stay in an area far beyond Pluto. Once in a while, one of these ice balls gets drawn into an orbit that brings it much nearer to the Sun. Asteroids are found much closer to Earth than most comets are. Most asteroids circle the Sun in the asteroid belt, a band that lies between the planets Mars and Jupiter. Meteoroids can come from many different areas in our solar system. Some meteoroids are formed when one asteroid collides with another. Other meteoroids were once part of a comet. How big are these different kinds of space rocks? Most asteroids are about the size of a house, but some are more than 100 km wide. The biggest asteroid, Ceres, is shaped like a ball and is about 975 km across at its equator-almost large enough to cover the width of Saskatchewan and Manitoba! A meteoroid can be almost as large as a small asteroid. Some meteoroids are the size of baseballs, but most are no bigger than a grain of sand. It's hard to say how big a comet is. Unlike asteroids and meteoroids, a comet's size changes depending on how close it is to the Sun. The nucleus of most comets is less than 10 km wide. That's about the size of a small town. But as a comet gets closer to the Sun, the ice on the surface of the nucleus turns to gas and forms a mist-like cloud, or coma, around the centre. That icy mist can flare out as far as 80 000 km-and that's not including the comet's tail!

Are any of these space travellers visible in the night sky? If you've ever seen a shooting star, then you've seen a meteor. On any clear night you can see about one per hour, without using binoculars or a telescope. At certain times of the year, many meteors streak through the night sky in a meteor shower. Compared to meteors, comets are much harder to see. You'll spot only one comet about every 10 years if you don't use a telescope or binoculars. Peering through one of those instruments, you'll be able to observe many more. Without the help of a telescope or binoculars, it's unlikely that you would ever glimpse an asteroid. Most are just not bright enough to be visible in a starry sky.

What can comets, asteroids, and meteoroids tell us about our past? By examining comets and asteroids with space probes or telescopes, experts can find out more about what was happening when the solar system formed approximately 4.6 billion years ago. Earth craters that were created by meteorite collisions can give hints about our planet's history. Some scientists think a huge meteor crashed into Earth about 65 million years ago, creating enough dust and smoke to blanket the planet and block out the Sun. The lack of sunlight would have killed plant life and eventually starved the dinosaurs into extinction. Comets, asteroids, and meteoroids are similar in some ways, and different in many others. But they're all space travellers that help us learn more about the universe and our planet.

Appendix E: Discussion Prompts

ToM story – Eric’s Bike

- Who was your favourite teacher when you were in elementary or high school, and why did you like them? Or, if not, was there a teacher you really didn’t like? Why?
- Mr. Howard could tell that Eric was struggling and gave him the bike when he needed it most. Tell about a time that someone did something to help you when you really needed it.
- Do you think Eric’s friends should have done more to help him or to ask about what was going on with him? Do you think you would have acted similarly if Eric was your friend?
- What were some things that you liked or didn’t like about this story?
- Talk about a time you received a great gift from someone.
- At the end of the story, Eric felt happy and free when he was riding the bike. Can you think of a time when you felt this way? What made you feel like this?

Non-ToM story – Space Travellers

- Did you learn anything new from this passage? What did you learn?
- What were some things you found interesting about this passage? Was there anything that you found confusing?
- If you found this passage boring, what are some other nonfiction topics you’d rather learn about? Why/what do you find interesting about these topics?
- Is there anything else you know about space? If so, what are some of the coolest/most interesting facts you know about space?
- Would you ever want to visit space?
- Do you think alien life exists? Why or why not? If you do, what do you believe about the nature of aliens?
- What do you think about the idea of colonizing mars?

Curriculum Vitae

Kate Turner

EDUCATION

Master of Science in Psychology (Cognitive, Developmental and Brain Sciences)

2021-Present

Western University
London, ON

- Thesis title: Investigating neural mechanisms associated with the Double Empathy Problem using fNIRS hyperscanning
- Supervisors: Dr. Ryan Stevenson, PhD & Dr. Bobby Stojanoski, PhD

Bachelor of Science (Honours) in Behaviour, Cognition and Neuroscience

2016-2020

University of Windsor
Windsor, ON

- Thesis title: The Effect of Abuse Type and Severity on Memory Challenge Outcomes
- Supervisor: Dr. Patti Fritz, PhD

RESEARCH EXPERIENCE

Researcher

2020-2021

University of Windsor, Windsor,
ON Supervised by Dr. Patti Fritz

Topics of research: thematic analysis of intimate partner violence, memory challenge, and women's responses to a partner challenging their memory

Research Assistant

2018-2019

University of Windsor, Windsor,
ON Supervised by Dr. Patti Fritz

CONFERENCE PRESENTATIONS

Turner, K., Stevenson, R. & Stojanoski, B. (2023). Using Interbrain Synchrony to Investigate Social Differences Associated with Autistic Traits. Virtual Oral Presentation to be presented at *Special Interest Research Group - Society for Neuroscience of Human Attachment: Interpersonal Synchrony and its Relevance for Attachment and Caregiving*, University of Essex, Colchester, UK in May 2023

Turner, K., Stevenson, R. & Stojanoski, B. (2023). Investigating Neural Mechanisms Associated with the Double Empathy Problem Using fNIRS Hyperscanning. Oral Presentation to be presented at *International Society for Autism Research Annual Meeting*, Stockholm, Sweden in May 2023.

Turner, K., Stevenson, R. & Stojanoski, B. (2023). Investigating Social Differences Associated with Autistic Traits Using fNIRS Hyperscanning. Poster presented at *Lake Ontario Visionary*

Establishment Conference, Niagara Falls, ON in Feb 2023.

Turner, K., Stevenson, R. & Stojanoski, B. (2022). Hyperscanning during social interactions between autistic and non-autistic individuals. Oral Presentation as part of Rapid Presentation Session presented at *WestNIRS*, Western University, London, ON in September 2022.

AWARDS AND ACHIEVEMENTS

Canadian Graduate Scholarship – Master’s	2022-2023
Social Sciences and Humanities Research Council Western University	
Degree awarded With Distinction	2020
University of Windsor	
Dean’s Renewable Entrance Scholarship (\$10,000 total)	2016-2020
University of Windsor	
Dean’s Honour Roll	2016-2020
University of Windsor	
Outstanding Scholars (\$1500)	2016-2017
University of Windsor	

CERTIFICATIONS

ADOS-2 Clinical Training	October 2021
University of Calgary	

WORK EXPERIENCE

Western University

Graduate Teaching Assistant
2021-2023
London, ON

Mathnasium

Instructor
2019-2021
Tecumseh, ON

Brain Injury Association of Windsor & Essex County

GOALS Group Facilitator
2019
Windsor, ON

VOLUNTEER EXPERIENCE

John McGivney Children’s Centre

2019
Windsor, ON

Brain Injury Association of Windsor & Essex County

2019

Windsor, ON

St. John the Baptist Catholic Elementary School

2016-2019

Belle River, ON

Let's Talk Science - University of Windsor

2019-2020

Windsor, ON 2019-2020