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Neural Synchrony In Successful Communication

Kristin Shumaker
University of Pennsylvania

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Abstract

Communicating our experiences to others relies on complex shared social, cultural, and psychological mechanisms. Research increasingly shows that shared neural mechanisms also play a role in the success of interpersonal communication. Synchronous activity in shared or complementary regions of the brain promotes emotional connections, cooperation, and memory between communicators. Regions of the brain involved in social and self-relevant information processes – (1) mentalizing, or thinking about the thoughts of others, and (2) self-relevance, or prospecting about the importance of information to the self – show synchrony in ways that correlate with communication outcomes. Synchrony can occur between two individuals, like speakers and their listeners, but it can also occur among a group of listeners, the audience. We use a form of neuroimaging called functional near-infrared spectroscopy to study neural activity as people tell and hear stories. First, we measure synchrony between storytellers and listeners. Chapter 2 shows that synchrony in mentalizing brain regions between a storyteller and her listeners predicts effective communication of emotional states. Next, we consider how synchrony across larger groups of audience members relates to successful communication. Chapter 3 demonstrates that an individual listener's similarity to the average brain response in other audience members, in self-relevance processing regions, predicts the listener's ability to authentically re-tell a story. Finally, extending this work, we also examine whether shared preferences predict neural synchrony in audience members. Chapter 4 integrates information about audience members' individual preferences for content with audience-level neural synchrony. Within audiences of sports fans and theater lovers, self-reported content preferences predict behavioral liking for entertainment, but neural synchrony does not predict similar preferences in this case. Together these studies explore how synchrony between individuals predicts understanding and ability to transmit stories.

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Supervisor of Dissertation

Emily Falk
Professor of Communication, Psychology and Marketing

Graduate Group Chairperson

John Jemmott
Kenneth B. Clark Professor of Communication and Psychiatry

Dissertation Committee

Joseph N. Cappella, Gerald R. Miller Professor Emeritus of Communication
Sandra González-Bailón, Associate Professor of Communication

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ABSTRACT

NEURAL SYNCHRONY IN SUCCESSFUL COMMUNICATION

Kristin Shumaker

Emily Falk

Communicating our experiences to others relies on complex shared social, cultural, and psychological mechanisms. Research increasingly shows that shared neural mechanisms also play a role in the success of interpersonal communication. Synchronous activity in shared or complementary regions of the brain promotes emotional connections, cooperation, and memory between communicators. Regions of the brain involved in social and self-relevant information processes – (1) mentalizing, or thinking about the thoughts of others, and (2) self-relevance, or prospecting about the importance of information to the self – show synchrony in ways that correlate with communication outcomes. Synchrony can occur between two individuals, like speakers and their listeners, but it can also occur among a group of listeners, the audience. We use a form of neuroimaging called functional near-infrared spectroscopy to study neural activity as people tell and hear stories. First, we measure synchrony between storytellers and listeners. Chapter 2 shows that synchrony in mentalizing brain regions between a storyteller and her listeners predicts effective communication of emotional states. Next, we consider how synchrony across larger groups of audience members relates to successful communication. Chapter 3 demonstrates that an individual listener's similarity to the average brain response in other audience members, in self-relevance processing regions, predicts the listener's ability to authentically re-tell a story. Finally, extending this work, we also examine whether shared preferences predict neural synchrony in

audience members. Chapter 4 integrates information about audience members' individual preferences for content with audience-level neural synchrony. Within audiences of sports fans and theater lovers, self-reported content preferences predict behavioral liking for entertainment, but neural synchrony does not predict similar preferences in this case. Together these studies explore how synchrony between individuals predicts understanding and ability to transmit stories.

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CHAPTER 1

Introduction

Storytelling and Successful Communication

Stories are powerful and pervasive; across time and cultures, stories convey attitudes, beliefs and norms along with a structured narrative of real or imagined events. A rich body of research examines how stories engage, transport and persuade listeners (Busselle & Bilandzic, 2009; Green et al., 2004; Green & Brock, 2000; Slater, 2002). Building on this literature on the psychological mechanisms of story comprehension, research using neuroscience methods has begun to uncover the neural mechanisms underlying narrative processing (Lerner et al., 2011; Regev et al., 2013; Yarkoni et al., 2008). But storytelling is not a solo act. The interplay between communicators – the storyteller and their listener(s) – influences the success of communication through storytelling. Using neuroimaging methods, 'second-person neuroscience' measures neural activity in the brains of two or more individuals, either simultaneously or sequentially, during social interaction (Redcay & Schilbach, 2019; Schilbach et al., 2013). These methods provide information about the similarity of neural activity between individuals, or their neural synchrony. Combining research into story comprehension with the methods of second-person neuroscience, this dissertation examines the role of neural synchrony during storytelling and listening in predicting successful communication.

Researchers define communication success in different ways. Generally, successful communication reflects a shared understanding of situations and interpretation of ambiguous information between the speaker and listener (Pickering & Garrod, 2006).

Listeners' ability to understand word meanings (Boer et al., 2013) represents success on a granular level, while their memory for factual information (Stephens et al., 2010) represents success at a higher level of abstraction. In broader terms, success may require effects on or subsequent action by listeners. Transmission of a message from a listener to others (O'Donnell & Falk, 2015) or changes to a listener's attitudes or behaviors from a persuasive message (E. Falk & Scholz, 2018) ensures that the message will continue to have real-world impact. In the context of this dissertation, successful communication occurs when listeners remember the facts of a story (Chapters 2 and 3), understand the emotional states of the storyteller (Chapter 2) and are able to transmit that story to others in an authentic way (Chapter 3). Successful communication also occurs when messages, such as entertainment content, appeal as intended to audiences of fans (Chapter 4).

Across three studies in this dissertation, we focus on two core systems in the brain that we hypothesize should play an important role in these forms of successful communication. First, understanding and anticipating the mental and emotional states of a communication partner (e.g., the storyteller or listener) may involve brain activity supporting people's understanding of others' mental states—a process known as mentalizing. Core components of the brain's mentalizing system include the right and left temporoparietal junctions (TPJs) and the dorsomedial prefrontal cortex (DMPFC) (Atique et al., 2011; Denny et al., 2012; Van Overwalle, 2009; Young et al., 2010).[1] Throughout the dissertation, we will also use the phrase "social brain regions" to refer to

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[1] Note: Other regions of the mentalizing system include precuneus, posterior cingulate and temporal poles; however, given the limitations of the functional near infrared spectroscopy (fNIRS) technology used for measurement in this dissertation, we focus on core mentalizing regions that are accessible on the cortical surface to fNIRS.

this system. Activity in these regions increases when individuals work to understand other people's thoughts and perspectives. Second, considering the relevance of communication messages to oneself recruits the medial prefrontal cortex (MPFC), among other regions that are not accessible to functional near infrared spectroscopy (fNIRS). Activity in the MPFC increases when listeners consider how message content is related to their experiences or otherwise relevant to them (Abraham, 2013; Fields et al., 2019; Lieberman et al., 2019). These regions are examined in greater detail within each study but, taken together, they index how individuals understand the perspectives of others and judge the importance of information to themselves.

In this dissertation, Chapter 2 asks whether synchrony between a storyteller and her listeners in social and self-relevance processing brain regions predicts the successful communication of emotions and facts. Chapter 3 shifts to the next step in the lifecycle of a story, sharing the story with new listeners. Examining self-relevance and social processing brain regions, we investigate whether synchrony among an audience of listeners predicts the successful re-transmission of a story. Finally, Chapter 4 expands on the question of synchrony in audiences, testing whether message content and the listener's preference for that content, matters to synchrony in social and self-relevance processing regions in the brain. Taken together, this dissertation investigates the relationship between neural synchrony in social and self-relevance information processing regions of the brain and different components of successful communication.

Stories as a Communication Device

Stories communicate events and individuals' reactions to them – including their thoughts, emotions and actions – within a given context, following a dramatic arc through time (S. Brown & Tu, 2020). These features drive individuals to engage with, be persuaded by, remember and retell stories (Busselle & Bilandzic, 2009; L. M. Gagnon & Dixon, 2008; Green & Brock, 2002).

One important goal in communication is for communicators to understand each other; stories facilitate emotional connections between storytellers and listeners in a variety of ways. Narrative transportation, or the tendency of listeners to feel as though they are inside the world of a story, relies on cognitive and emotional processes within story listeners (Green & Brock, 2000). Often, transportation creates enjoyment of a story and feelings of connection to story characters (Green et al., 2004). Beyond liking or feeling for story characters, listeners who identify with characters often imagine themselves in the shoes of the character, taking the character's perspective. Character identification incorporates empathy with the story character, suggesting an important role for both perspective taking and empathy in a listener's experience of a story (Cohen, 2001).

Autobiographical stories, which convey real-life experiences, are commonly shared in spontaneous, everyday conversations (Norrick, 1998, 2007). Sharing autobiographical stories fulfills important social functions, including relationship building and maintenance, teaching and informing others, and eliciting or providing empathy (Alea & Bluck, 2003). Retelling stories with increased detail and emotional content strengthens interpersonal bonds, makes story content seem more credible and persuasive and makes the storyteller more relatable to their listener (Alea & Bluck, 2003, 2007). In addition to people telling and retelling stories about their own experiences, autobiographical stories can be borrowed by others, who retell the stories as their own, often to improve their social connection with their listeners (A. S. Brown et al., 2015). Over a quarter of people who borrowed others' stories later experienced confusion about whether the borrowed story happened to them or to someone else, suggesting some incorporation of the borrowed story into their autobiographical memory (A. S. Brown et al., 2020). Stories are readily incorporated into memory, although how we remember them may depend on our motivation for sharing the story in the future. When people are instructed to listen to and retell an autobiographical story, memory for story facts is greater when accuracy, rather than entertainment, is the goal of retelling (Dudukovic et al., 2004). When retelling stories with a delay between story listening and retelling, individuals who have an entertainment goal include fewer factual details, and show more re-ordering of story events and invention of false details than individuals who were instructed to be accurate (Dutemple & Sheldon, 2022). As much as stories stick in our memory, our memory for story events, and even whether the story is actually autobiographical, is not infallible.

Autobiographical stories also serve to elicit empathy from listeners. Over the duration of a story, emotional content changes in valence and strength as a function of its dramatic arc (S. Brown & Tu, 2020). Likewise, the storyteller's emotional state changes as they tell their story. Empathy is the process by which individuals identify, understand and respond to the thoughts and feelings of others (Zaki, Weber, et al., 2009). Empathy is frequently divided into two processes: experience sharing and mentalizing (Zaki &

Ochsner, 2012). In the storyteller – listener context, experience sharing involves the listener experiencing the internal states of the storyteller in an embodied manner. Mentalizing occurs when the listener identifies and understands the storyteller's internal states (i.e., thoughts and feelings) or when the storyteller imagines the perspectives of their audience. In the brain, mentalizing activates the previously mentioned social brain regions. In a study of autobiographical storytelling about chronic pain, participants who shared their own emotional autobiographical stories showed increased empathy for an original storyteller experiencing chronic pain, but participants who retold the original story or recalled a self-chosen movie scene of a character in pain did not show the same empathic response (Bluck et al., 2013). As a hallmark of successful communication, empathy between communicators can lead to joint physical and physiological action.

Synchrony in Communication

Although the term 'synchrony' is colloquially used to represent various interpersonal dynamics from joint action to looser coordination between communicators, Semin (2007) defines synchrony as 'jointly and simultaneously recruited process[es]' shared between 'the sender and receiver of a communicative act.' Crucially, synchrony between communicators occurs in part at the neural level, where neural mechanisms precede any behavioral action or utterance (Semin, 2007). Synchronous processes occur across a spectrum from easily observable behaviors to outwardly imperceptible physiological and neural processes. Actions or behaviors are measured by observation, while physiological and neurological synchrony require tools to measure and interpret. Interpersonal synchrony across these levels, from behavioral to physiological to neural, are all related to communication outcomes.

Both behavioral and physiological synchrony independently predict elements of successful communication. Observable behaviors, including synchronous movement and eye gaze coordination, predict word recall (Macrae et al., 2008), mutual understanding between communicators (Shockley et al., 2009) and coordination with an outgroup member (Miles et al., 2011). Synchrony in heart rate predicts memory for a story (P. Pérez et al., 2021). Physiological synchrony predicts emotional similarity between non-interacting audience members during movie viewing, suggesting that just being co-present with others affects how people experience stories (Golland et al., 2015). Individuals with communication disorders, such as autism spectrum disorder (ASD), show less behavioral synchrony with both neurotypical individuals and with others who share an ASD diagnosis (Georgescu et al., 2020). In children with ASD, lack of movement synchrony with communication partners predicted a lack of verbal communication skills (Zampella et al., 2020).

While behavioral and physiological synchrony are associated with communicators recalling information and sharing emotions, evidence increasingly shows that shared activity across brains is also linked to these mechanisms (Hoehl et al., 2021). In some cases, behavioral synchrony alone produces neural synchrony. For instance, synchronous finger movement in a cooperative, nonverbal task produces neural synchrony between individuals in both the motor cortex and in prefrontal areas associated with implicit social interaction (Yun et al., 2012). Behavioral and physiological synchrony form a feedback loop with brain activity, whereby neural mechanisms also create synchrony in interpersonal interactions (Kingsbury & Hong, 2020). An increasing body of literature shows that even complex social interaction – combining nonverbal and verbal communication – produces synchrony across the brains of communicators.

Synchrony in the Brain

A recent review of 29 studies of neural synchrony during spoken communication found evidence for synchrony across multiple communication paradigms, including conversation and storytelling, and neuroimaging technologies (Kelsen et al., 2020). Similarities in semantics and linguistic style predict attention and engagement in conversation, as well as how much communicators talked with each other and engaged in self-disclosure (Babcock et al., 2014; Niederhoffer & Pennebaker, 2002). Alignment in spoken language is related to alignment between communicators' brains (Menenti et al., 2012). Speech production and comprehension recruit overlapping regions of the brain, including the bilateral temporoparietal junctions (TPJs) and the medial prefrontal cortex (MPFC) mentioned above (Silbert et al., 2014). Synchrony between the brains of communicators indexes the predictability of the speaker's language, suggesting that neural synchrony is greater when listeners can correctly anticipate the speaker (Dikker et al., 2014).

In the past two decades, technological and methodological developments have started to address a core challenge in neuroimaging: imaging during naturalistic social interaction. Dubbed "second-person" neuroscience, these studies collect brain data from one or two individuals, usually the communication receiver or both the sender and receiver, either sequentially or simultaneously during interaction (Redcay & Schilbach, 2019; Schilbach et al., 2013). Neural synchrony is typically expressed as intersubject correlation (ISC), or the correlation between the brain activity in participant A and the brain activity in participant B, in a given region of interest over the task duration (Nastase et al., 2019). In this way, second-person studies often report the similarity of neural activity across individuals rather than the amount – increase or decrease from baseline – of activity. Hyperscanning, or measuring two brains simultaneously, may employ real-time or delayed designs. Sequential scanning of two brains (e.g. scanning the sender first while they communicate, then scanning the message receiver) only allows investigations in unidirectional communication, but is sufficient for questions about information flow and how individuals represent other's mental states (Konvalinka & Roepstorff, 2012). Sequential second-person designs, such as those included in this dissertation, are particularly useful when the stimuli of interest are complex and dynamic, such as movie viewing or storytelling (Redcay & Moraczewski, 2020).

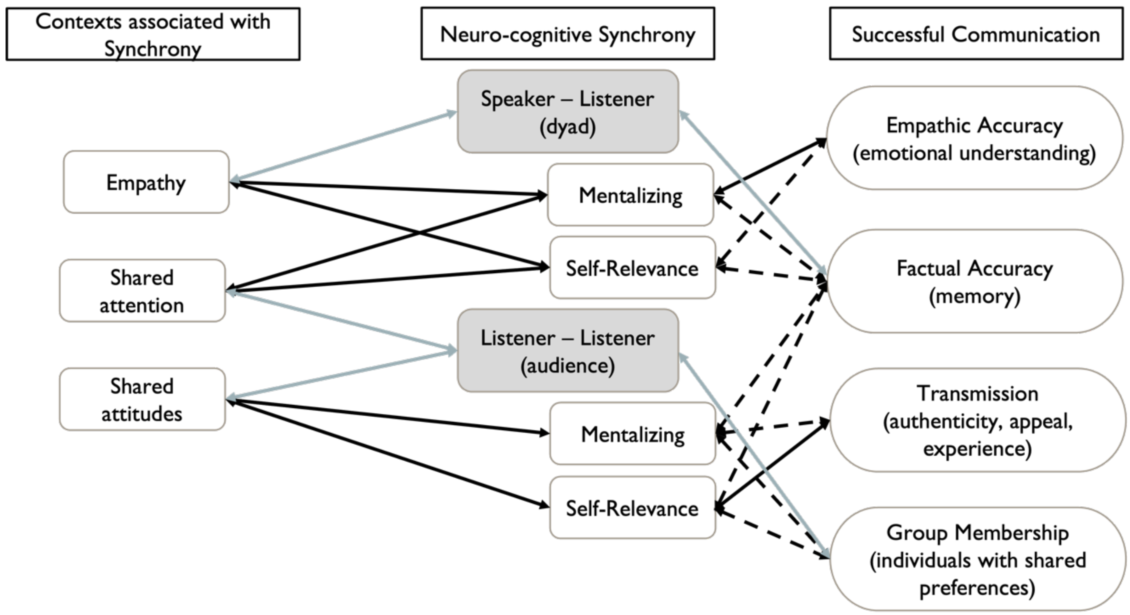
Choosing an appropriate neuroimaging modality is key to preserving the ecological validity of naturalistic communication tasks (Kinreich et al., 2017). Many studies of neural synchrony are conducted with functional magnetic resonance imaging (fMRI), which provides spatially-specific data from the whole brain, but requires that individuals remain stationary inside large magnetic scanners (Misaki et al., 2021). Wearable neuroimaging systems, which use external sensors placed on the scalp, minimize restrictions on individuals during communication tasks. Electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS), both wearable systems, measure brain activity using cortical electrical activity and near-infrared light, respectively (A. Pérez et al., 2017; Wallois et al., 2012; Yücel et al., 2017).

The studies in this dissertation use fNIRS to measure synchrony between communicators and in audience groups. Similar to fMRI, fNIRS measures the bloodoxygen level dependent (BOLD) signal as a proxy for activity in localized areas in the brain. fNIRS provides two measures, the change in relative concentrations of oxygenated (HbO) and deoxygenated (HbR) hemoglobin, as markers of neural activity (Scholkmann et al., 2014). While fNIRS has limitations in the depth at which it can measure activity in brain tissue and its spatial specificity, studies have validated fNIRS against fMRI results in physical (Noah et al., 2015) and cognitive tasks, including storytelling (Y. Liu et al., 2017; Stephens et al., 2010). fNIRS is often used in studies of verbal communication because it is tolerant of head movement, comfortable to wear, allows participants to be measured either in a lab or naturalistic environment and can be designed to simultaneously measure two or more individuals (Ferrari & Quaresima, 2012).

Previous studies of neural synchrony in communication, using different modalities, relate synchrony to a variety of outcomes relevant to successful communication, broadly defined. Figure 1.1 summarizes the theoretical bases for key relationships between the behavioral antecedents of neural synchrony with neural synchrony and communication outcomes. In addition to behavioral antecedents, many message-level features such as message strength (Imhof et al., 2020; Schmälzle et al., 2015), emotionality (Nummenmaa et al., 2014) and predictable language (Dikker et al., 2014) have been linked to neural synchrony; in this dissertation, we focus primarily on qualities of the communicator and dyad, such as empathy, shared attention and shared attitudes. Connections included in this dissertation are labeled with black arrows; dashed lines represent hypothesized relationships between synchrony and communication outcomes, while solid lines represent relationships supported by findings in this dissertation. Other relationships supported by the literature are labeled in gray, and included as context about how we think about these relationships. We use bidirectional arrows to highlight relationships between antecedents and synchrony, as well as synchrony and communication outcomes, because the relationships between neural synchrony and its antecedents are often bidirectional, where a behavior may produce neural synchrony, and neural synchrony may reinforce a behavior. Further, bidirectional arrows are appropriate since all relationships in this dissertation are tested as correlations, rather than experimentally. It is also important to note that synchrony is measured in two ways – between communicators, as in a speaker-listener dyad, or across a group of people, comparing individuals who listen to the same message – and that these measurements are theorized to predict different communication outcomes. It should also be noted that although we refer to "successful communication" in different parts of this dissertation, we use this shorthand as a way to conceptually link a range of different, particular operationalizations, detailed in Figure 1.1 and noted in each chapter.

Figure 1.1

Theoretical Model of Synchrony Predicting Successful Communication



Note. Relationships between the behavioral antecedents of synchrony with neural synchrony and communication outcomes. Arrows labeled in black indicate relationships hypothesized in this dissertation; dashed lines are hypothesized but unsupported by the current research, while solid black lines represent relationships supported by findings in this dissertation. Other relationships that are directly supported by the literature are labeled in gray. We view it as plausible that additional relationships could link the highlighted antecedents with neuro-cognitive synchrony in mentalizing and self-relevance systems. Although not yet tested in the literature, missing connections (e.g., shared attitudes predicting speaker-listener synchrony) represent areas for future research.

In persuasive communication, strong messages collectively drive audience engagement, and hence increased synchrony among audience members predicts the strength of political speeches (Schmälzle et al., 2015) and health messages (Imhof et al., 2020). Emotional speech also creates neural synchrony across individuals, with negative emotion increasing ISC between listeners (Nummenmaa et al., 2014). During coordinated action with another person, as opposed to a computer, greater intersubject correlation in the brain produces greater prosocial and helping behaviors (Hu et al., 2017). Actively generating ideas in a collaborative problem solving task produces greater ISC than contributing common, pre-written ideas (Lu & Hao, 2019), as does cooperation over independent play during a game of Jenga (N. Liu et al., 2016).

Memory and learning also benefit from neural synchrony. Individuals who viewed the same movie show similar neural activity across brains during both viewing and recall, with changes in similarity predicting memory for movie content (Chen et al., 2017). Neural synchrony during movie viewing predicts social closeness in friendship networks (Parkinson et al., 2018). Synchrony among students during a science lesson predicts scores in both immediate and delayed tests, while test performance was predicted by a time-delayed coordination between the brains of the teacher and their students (Davidesco et al., 2019). Teacher-student neural synchrony not only predicts learning outcomes, but is significantly greater in question- versus explanation-based teaching approaches (Pan et al., 2020). More broadly, ISC predicts social status, with more popular individuals showing greater synchrony with others (Baek et al., 2022).

The relationship between neural synchrony and the successful communication of stories extends these findings to a complex social communication behavior. As previously mentioned, basic mechanisms of verbal communication, including speech production and comprehension (Silbert et al., 2014) and identification of predictable language (Dikker et al., 2014), are closely related to neural synchrony. The influence of synchrony on memory and other forms of social cognition also supports the idea that neural synchrony can predict the myriad processes that comprise successful communication of stories. In an fMRI study, Stephens and colleagues (2010) establish that storyteller-listener synchrony exists only when communicators share a common language and when they are telling or hearing the same story, rather than different languages or stories. They also show that synchrony predicts the listeners' memory for story facts, a fundamental measure of successful communication (Stephens et al., 2010). These results were validated in an fNIRS study, where synchrony in oxygenated hemoglobin (HbO) as a proxy for brain activity predicted story comprehension and a direct analysis of fNIRS and fMRI data for two groups of story listeners showed significant correlation only when they heard the same story (Y. Liu et al., 2017). Interestingly, this fNIRS replication did not report whether storyteller-listener neural synchrony predicted memory for the story. A recent review of narrative processing and propagation in the brain supports the idea that ISC predicts the success of narrative communication, and attributes the processing of narrative to brain structures including areas of the medial prefrontal cortex and the bilateral temporoparietal junctions, which should be accessible to fNIRS (Ferrari & Quaresima, 2012; Jääskeläinen et al., 2020). These regions are involved in attention and memory, as well as processing social and self-relevant information.

Social and Self-Relevance Processing in the Brain

Across three studies in this dissertation, we focus on two core systems in the brain that we hypothesize should play an important role in successful communication. First, understanding and anticipating the mental and emotional states of a communication partner (e.g., the storyteller or listener) recruits areas involved in social information processing. These social brain regions include the bilateral temporoparietal junctions (TPJs) and the dorsomedial prefrontal cortex (DMPFC), as well as other regions (e.g. precuneus, posterior cingulate cortex) not accessible to measurement using fNIRS (Ferrari & Quaresima, 2012; Kliemann & Adolphs, 2018). Collectively, these regions are also known as the mentalizing system, since they are preferentially activated during tasks which require "mentalizing," or understanding other people's thoughts and perspectives.

Although both the left and right TPJs are recruited during mentalizing, the hemispheres show some specialization for different types of mentalizing tasks. Classically, the right TPJ responds more strongly to explicit theory-of-mind tasks, particularly false belief tasks, than the left TPJ (Young et al., 2010). Mentalizing scenarios which provide justification for another's belief also preferentially activate the right TPJ over scenarios which provide no information about why the agent has a given belief (Koster-Hale et al., 2017). The left TPJ responds to a broad range of social information. Activity in the left TPJ after meaningful conversations between romantic partners predicts partner well-being (Dodell-Feder et al., 2016). In story listening, the left TPJ is active when identifying social versus non-social stories, identifying a story character as self or other and interpreting whether the character's attention shifts between objects exogenously or endogenously (Guterstam et al., 2021). In general, however, a meta-analysis of the literature on mentalizing suggests that both the right and left TPJs aid in representing the mental states of others, and in distinguishing those others' states from the self (Quesque & Brass, 2019).

A third region in the mentalizing system, the dorsomedial prefrontal cortex (DMPFC), is part of the larger medial prefrontal cortex, which contains an interesting functional gradient in information processing. Studies have variously divided the medial prefrontal cortex into two (Van Overwalle, 2009) or three (Frith & Frith, 2006; Lieberman et al., 2019) subregions along the dorsal-ventral axis. A meta-analysis of self versus other tasks suggests that although much of the medial wall is implicated in both self and social processes, the dorsal subregion, the DMPFC, is more associated with making judgments about others, while more ventral areas of the MPFC are more associated with making judgments about the self (Denny et al., 2012). A recent mega-analysis of self versus other tasks suggests that the social and self-relevance processing in the MPFC might not be strictly linear from dorsal to ventral MPFC, but does confirm greater activation for social information processing in the DMPFC (Parelman et al., 2021). However, there is broad consensus that DMPFC is involved in mentalizing. For example, during a prompted story imagination task, DMPFC activity predicted which one of four target characters was being imagined in a given trial (Hassabis et al., 2014). The ability to mentalize also predicts real-world social behaviors, with individual differences in DMPFC activity during viewing of social scenes predicting time spent around other people (Powers et al., 2016). In the context of this dissertation, we focus on DMPFC as a region of interest that helps people understand others' mental states as part of the mentalizing system.

The second core system for successful communication processes the self-relevance of information. Whether a message is narrative or non-narrative, the anterior MPFC (here, referred to as the MPFC), responds to self-relevant information; from explicit trait judgements to remembering past events, MPFC activity indexes self-relevance (Lieberman et al., 2019). Judging trait relevance to the self versus another person produces greater activation in the MPFC (Kelley et al., 2002). In a similar trait relevance task, MPFC activity was greater for self-relevant versus irrelevant traits and also predicted memory for the trait adjectives used in the task (Macrae et al., 2004). Outside of trait judgments, MPFC activity is also related to autobiographical memory and mental time travel. Retrieving autobiographical memories, the past episodes which form the basis of autobiographical stories, activates the MPFC (Spreng et al., 2009). Imagining the future for the self, or even imaging fictional pasts and futures, also produces activity in the MPFC, suggesting that mental time travel for events that have not, or have not yet, happened recruits the same neural regions as remembering lived events (Lieberman et al., 2019). Conceptions of the actual self from the past and the possible self in the future both contribute to autobiographical stories, suggesting that storytellers may recruit the MPFC, while listeners recruit the MPFC to judge any message content, whether narrative or not, as relevant or irrelevant to themselves.

Dissertation Overview

In three studies, this dissertation explores the neural mechanisms of successful communication through stories, with a particular focus on mentalizing and self-relevance brain systems. Chapter 2 examines whether storyteller – listener synchrony in social and self-relevance processing brain regions (i.e., left and right TPJ, DMPFC, MPFC) predicts the successful communication of emotion and facts in a story. Chapter 3 moves to the question of story transmission, asking if synchrony among an audience of listeners in these same regions predicts whether a retelling is believed to be authentic. Finally, Chapter 4 expands on the question of synchrony in audiences, testing whether message content, and the listener's preference for that content, produces greater neural synchrony in people who share preferences. Together, these studies investigate the relationship between neural synchrony in self-relevance and social information processing regions of the brain and different components of successful communication.

CHAPTER 2

Speaker-listener synchrony predicts empathic accuracy in storytelling

Abstract

Successful communication of a story often depends on the storyteller's ability to convey emotional content, and the listener's ability to understand those emotions. Empathic accuracy is a measure of that ability to identify the storyteller's thoughts and feelings. Synchrony – in physical movement and physiology – between communicators is related to empathy and emotional understanding. Sharing and understanding emotions fosters feelings of social closeness and connection that underlie communication success. Using functional near infrared spectroscopy (fNIRS), this study tests whether neural synchrony between a storyteller and her listeners predicts the empathic accuracy of the listener. Listeners (n = 77, female) heard an autobiographical story from a female storyteller. After the initial listening, they heard the story a second time, providing a continuous rating of their perceptions of the storyteller's emotional state throughout the story. We calculated empathic accuracy from this continuous rating data, and used the measure of neural synchrony (intersubject correlation; ISC) to predict the behavioral outcome. Participants also provided a retelling of the story, demonstrating their memory for story facts as a measure of factual accuracy. We found limited support for our hypotheses. Results show that speaker-listener ISC in the left temporoparietal junction, a region previously related to mentalizing about the thoughts and feelings of others, predicts the listener's empathic accuracy, although the relationship varies by the cognitive demands of the task and the exposure of participants to a compassion training manipulation. We did not observe significant relationships between ISC and empathic

accuracy in other regions of interest. These results provide limited support for the idea that synchrony in mentalizing activity reflects the accurate understanding of emotional autobiographical stories, under some circumstances.

Introduction

Successful storytelling requires listeners to understand both the story and the storyteller. Research shows that shared understanding and shared emotions between communicators promotes feelings of understanding and social closeness (Reis et al., 2017; Sened et al., 2017). Listeners' ability to accurately identify the storyteller's emotional states, as well as remembering story facts, may influence communication success. In this study, we measure whether neural synchrony between a storyteller and her listeners predicts the listener's ability to both accurately identify the storyteller's emotional states and accurately recall story facts.

Sharing emotional stories promotes empathy between communicators and listeners, which is important to our interpersonal relationships and feelings of social connection. Accurately understanding and responding to another's emotional display can create feelings of connection and promote positive relationship outcomes (Reis et al., 2017). In the context of interpersonal storytelling, empathic accuracy measures the listener's ability to infer the storyteller's emotional states and how they change over the course of the story (Ickes, 1993). Empathic accuracy on the part of the listener contributes to feelings of satisfaction for both the listener and speaker in a communication dyad (Sened et al., 2017). Following Zaki, Bolger and Ochsner (2009), empathic accuracy is measured by correlating the speaker's continuous rating of how positive or negative she felt while telling her story with each listener's continuous rating of how positive or negative they thought the speaker was feeling as she spoke.

Theories of empathy posit that empathy in part is subserved by synchrony between the speaker and listener (Zaki et al., 2008; Zaki, Weber, et al., 2009). Empathy is broadly divided into two systems: affective empathy, or experience sharing, where a listener vicariously takes on the speaker's internal states and cognitive empathy, or mentalizing, in which the listener is able to take the speaker's perspective and make inferences about their state of mind (Zaki & Ochsner, 2012). Jospe and colleagues (2020) measured heart rate synchrony, as a proxy for experience sharing, and a continuous rating correlation of empathic accuracy, as a measure of mentalizing, and found that physiological synchrony is not necessary for listeners to exhibit a high degree of empathic accuracy with the speaker when they watch and listen to a video-recorded autobiographical story. Synchrony in the neural mechanisms of mentalizing, then, may contribute to the degree of empathic accuracy between a speaker and her listeners.

In parallel with studies of empathy and empathic accuracy, research into memory for stories and the accuracy of factual recall suggests a role for speaker-listener neural synchrony. Stephens and colleagues (2010) found that synchrony in regions of the brain involved in mentalizing predicts the factual accuracy of the listener's story recall. Remembering the facts of a story requires encoding story events in memory; for effective encoding, the listener must attend to the story and share in the storyteller's knowledge of the social schemas activated in the story (Marsh, 2007). Stories are generally better recalled than expository texts, partly due to the familiar social contexts of personal narratives (Mar et al., 2021). Neural synchrony between teachers and students, as well as among students, predicts both immediate and delayed memory for lecture materials (Davidesco et al., 2019). In addition to predicting factual accuracy during story recall, neural synchrony among listeners also predicts periods of engagement with a story; the more engaging one group of participants found specific story events, the greater neural synchrony within a separate audience group for the story (Song et al., 2021).

Identifying the speaker's emotional states and engaging with and remembering the details of a story recruit psychological processes related to mentalizing about others and thinking about the self. Two neural systems for social and self-relevance information processing are likely to support these behaviors. Mentalizing, or understanding others' thoughts, feelings and perspectives, recruits the bilateral temporoparietal junctions (TPJs) and the dorsomedial prefrontal cortex (DMPFC), among other regions.

The right and left TPJs show greater activity for stories describing the beliefs of a character than stories which describe the physical world (Young et al., 2010). Both mentalizing about other's beliefs and intentions activates the TPJs bilaterally (Atique et al., 2011). Activity in mentalizing regions occurs for both listeners and speakers during a storytelling task (Silbert et al., 2014; Stephens et al., 2010). Generating stories from a prompt and sharing them through either speech, gesture or drawing produced bilateral TPJ activity (Yuan et al., 2018).

Another region recruited in the mentalizing system, the DMPFC, processes social information, with particular roles in story comprehension and interpersonal empathy. A review of task-related activity in the MPFC found that the DMPFC is reliably activated in social information processing tasks, such as understanding the thoughts and feelings of others (Lieberman et al., 2019). In story comprehension, DMPFC showed greater activation during story reading than baseline, but did not show a change in activation when reading scrambled sentences, suggesting that DMPFC activity is related to narrative organization (Xu et al., 2005; Yarkoni et al., 2008). During interpersonal interactions, DMPFC activity predicts prosocial behavior and greater empathy for dissimilar others, suggesting that mentalizing activity in the DMPFC may be associated with increased empathy and prosociality (Majdandžić et al., 2016).

A related neural system of interest is involved in processing self-relevant information. Judging trait adjectives as relevant versus irrelevant to the self recruits the medial prefrontal cortex (MPFC; among other regions not accessible to fNIRS), a region of the prefrontal cortex ventral to the DMPFC region involved in mentalizing. MPFC activity also increases memory for self-relevant trait words (Macrae et al., 2004). In addition to explicitly judging trait relevance, MPFC activity is related to general self-knowledge, making references to the self and autobiographical memory (Lieberman et al., 2019). Given the focus in this study on autobiographical storytelling, the role of the MPFC may represent either or both self-relevance judgments – especially in the case of activation in listeners – and autobiographical memory recall, particularly in the storyteller, or other related social cognitive processes.

We hypothesize that brain activity in the mentalizing system of the speaker and her listeners will be correlated. In our first analysis, we examine mentalizing activity while the speaker is speaking and the listener is listening. In this case, synchrony might occur if both the listeners and the speaker are thinking about characters in the story at the same moments, following the story arc. A related possibility is that the speaker might think about her own past mental states while she is engaged in storytelling, and the listeners might similarly consider her mental state at relevant points in the story. Both of these possibilities would produce positive speaker-listener correlations in the mentalizing system. An alternative is that the speaker might use her mentalizing resources to consider what her audience might think of her. While the listeners are thinking about the thoughts of story characters, including the speaker as the central character, the speaker could be thinking about how her audience will understand particular story events. Mentalizing synchronously with her listeners could indicate thoughts about adjusting her storytelling to make events relatable for her listeners, while listeners are thinking about story events, but this scenario would be less likely to result in speaker listener synchrony within the mentalizing system.

We also examine the correlation between speaker-listener mentalizing activity when both are performing the same listening task. When both the speaker and listener are listening to the original story and rating the speaker's emotions, more similar recruitment of mentalizing may indicate a shared understanding of the speaker's emotions, leading to greater empathic accuracy on the part of the listeners.

Finally, ISC in the MPFC, during either speaking and listening or when both speaker and listener are listening, could happen if the story similarly engages self-relevant thoughts or processing in the speaker and listener, and may represent similar understanding of emotions and lead to greater empathic accuracy.

The Current Study

In this study, we investigated whether greater synchrony in brain activity between a storyteller and listeners in regions tracking self-relevance and mentalizing predicted accurate interpersonal communication.

Hypotheses

H1: Neural synchrony and empathic accuracy: Greater neural synchrony (ISC) within regions of interest involved in a) mentalizing and b) self-relevance processing during exposure to the speaker's autobiographical story will be associated with higher empathic accuracy in the listener.

H2: Neural synchrony and factual accuracy: Greater neural synchrony (ISC) within the regions of interest involved in a) mentalizing and b) self-relevance processing will be associated with greater likelihood of the listener accurately recalling details of the speaker's story during story retelling.

Methods

Overview

Participants responded to a pre-recorded video of a storyteller sharing emotional past life events. We examined two indices of communication success: (1) empathic accuracy, or how accurately listeners empathize with the storyteller's emotions, and (2) factual accuracy, or the listener's ability to recall facts from the story. Pairwise speaker-listener intersubject correlations (ISC) were calculated from the fNIRS data within regions of interest implicated in mentalizing and self-relevance processing. We focused on speaker-listener ISC within the left and right TPJs and the DMPFC based on their previously shown roles in mentalizing about the thoughts and emotions of others (Atique et al., 2011; Young et al., 2010; Yuan et al., 2018) and within the MPFC based on its role in judging the relatedness of information to the self (Lieberman et al., 2019; Macrae et al., 2004). Our logic is that greater synchrony in these regions might track accuracy because the speaker and her listeners are simultaneously thinking about the thoughts of the story characters, and their own thoughts and feelings; in the speaker's case, this would require her to think about her past emotional states. In addition to these regions, we also tested the relationship between ISC and our outcomes of interest in the left and right temporal regions, due to potential overlap with the TPJ regions, and their functional role in mentalizing (Frith & Frith, 2006). Mean ISC for each ROI was then used to predict empathic accuracy and factual accuracy.

Participants

Female participants (n=77, M_{age} = 21.16, SD_{age} = 1.91; 71 White, 1 Asian, 1 Hispanic, 2 Mixed, 2 Other) were recruited from the University of Pennsylvania. Six participants were excluded from all analyses due to incomplete data (withdrawal from the study [n=4], poor signal in calibration [n=1] and corrupted data files [n=1]). Two additional participants were excluded from analysis for the story listening task only due to data corruption. In data analysis, n=69 participants were included in the story listening task data and n=71 participants were included in the emotion rating task data.

One additional female participant (age = 24), known to the research team but not otherwise involved in research at the University of Pennsylvania, was selected to serve as the storyteller. She told two unrehearsed stories about emotional, autobiographical events while undergoing fNIRS recording, with the opportunity to tell each of the two stories twice. The research team chose the first telling of the first story as the stimulus for the study based on two sets of factors: (1) the quality of the fNIRS data (i.e., absence of artifacts, signal-to-noise ratio) and (2) narrative features, including the length of the story, verbal fluency, and the organization and continuity of the story events.

Compassion Training Condition

The present data were collected as part of a collaborative project that also investigated the experimental effects of a compassion training manipulation on speaker-listener communication. The focus of this dissertation paper is on naturalistic, un-instructed story listening, so multiple analyses are run on the data to account for effects of condition on the relationship between neural synchrony and our accuracy measures of interest. All preregistered analyses are run over all study participants (both conditions), but we also ran exploratory interaction analyses to better understand the effects of synchrony under different psychological conditions. Specifically, participants were randomly assigned to one of two conditions; in the compassion condition (n = 34 (available clean data within the story listening task); 36 (available clean data within the emotion rating task)), participants completed a task designed to increase compassion for others by making positive wishes for known and unknown others prior to story listening. The remaining participants (n = 35) completed a control condition where they thought positively about others' efficacy at completing mundane tasks (e.g., doing laundry).

Story Listening Task

Following the compassion training or control task, each participant listened passively to a real, autobiographical narrative about an emotional event in the storyteller's life. Participants were instructed to listen without verbally responding, and were told they would be asked to respond to the story later. See Appendix A for a transcript of the story.

Emotion Rating Task

Following the story listening task, each participant heard the story for a second time. Participants were instructed to rate, using the same continuous rating slider, how positively or negatively the storyteller felt while she was speaking; task instructions differentiated between the storyteller's affect during speaking versus her feelings during the events taking place in the story. We used this rating information to calculate empathic accuracy; participants' perceptions of the story teller's emotions were correlated with her own ratings of her affect during her original storytelling (i.e., how she was feeling while she was speaking). This task provided the baseline measure of the storyteller's true feelings. See the *Analysis* section for details on the calculation of empathic accuracy.

Story Retelling Task

After hearing the story twice, each listener then recorded themselves retelling the story. Participants were instructed to tell the story in the first person, as though they had experienced the story events themselves. In this study, these retellings were used to establish the listeners' memory for story events and event details, or factual accuracy. See the *Analysis* section for details on the coding and calculation of factual accuracy.

fNIRS Data Collection

Functional near-infrared spectroscopy (fNIRS) data from the storyteller and all listeners were collected on a NIRx Scout system with 32 sources and 32 detectors (www.nirx.net). fNIRS measures the relative concentrations of oxygentated (HbO) and deoxygentated (HbR) hemoglobin in the blood, as a proxy for neural activity. Although HbO typically shows stronger effects in ISC literature (Cui et al., 2011; Y. Liu et al., 2017; Strangman et al., 2003), HbR is less correlated with physiological signals such as respiration and heart rate, and can be more spatially specific (Dravida et al., 2017; Yücel et al., 2021). As the primary measure of interest, HbO results are included in the main paper, with HbR results in Appendix A.

The fNIRS cap montage contained 102 source-detector pairs, with each pair forming a channel. The channels were distributed over the whole head on the International 10-20 system (Homan et al., 1987). The 102 channels were aggregated into twelve regions of interest, using anatomical literature to map 2D channels to 3D brain space (see Appendix for montage design). The MNI coordinates of each channel midpoint were determined using the fOLD toolbox (Zimeo Morais et al., 2018). ROI assignment was made based primarily on inclusion of the MNI coordinates of the channel midpoint in the AAL2 (Rolls et al., 2015) and OBART (Bohland et al., 2009) anatomical atlases. As a secondary factor, inclusion of that channel in pre-designed montages from NIRx (e.g., channel exists in the "MPFC" montage) was also considered. For all channels in the included ROIs (MPFC, DMPFC, bilateral TPJs, bilateral temporal and visual cortex), the anatomical and NIRx montage assignments were in agreement. Data were recorded at 1.95 Hz.

Analysis

Calculating Empathic Accuracy

Empathic accuracy was calculated as the Pearson correlation between the continuous rating measures of the storyteller and each listener over the duration of the story. Affect was measured on a slider scale from -5 to 5, labeled "Negative" and "Positive" at the respective ends, and "Neutral" at the zero midpoint. Measurements were recorded every 50ms over the 279 second duration of the story. Measurements were downsampled to 1 Hz and the Pearson correlation for each speaker-listener pair was calculated over the story duration. Empathic accuracy correlation values ranged from 0.484 to 0.936 (M= 0.76, SD= 0.09).

Calculating Factual Accuracy

Factual accuracy was determined by the inclusion of 66 facts from the original story in each participant's story retelling (see Appendix A for the accuracy rubric). Two independent coders, blind to participant condition, scored the presence or absence of each fact in all retold versions of the story. Tie-break decisions about whether or not the participant mentioned the fact were made by a senior member of the study team. Factual accuracy values ranged from 25 to 57 (M=43.89, SD=6.67).

Brain Regions of Interest

As noted in the introduction, we are interested in brain regions involved in social and self-relevance information processing. The mentalizing system, comprised of the bilateral temporoparietal junctions (TPJs) and the dorsomedial prefrontal cortex (DMPFC) responds preferentially to social information which requires parsing the mental states of others (Van Overwalle, 2009). The self-relevance processing system activates the medial prefrontal cortex (MPFC), which responds both to explicit judgments about the self as well as recall of autobiographical memories (Lieberman et al., 2019). Both systems could be recruited by the speaker telling their story or the listener hearing the story, as mentalizing, self-relevance processing and autobiographical memory recall are all important to generating and processing autobiographical stories. In addition to these regions, we have included three additional regions. The bilateral temporal regions are adjacent to the TPJs; due to differences in cap placement and lack of spatial normalization of channels between participants, adding these regions allows us to cover more of the temporal-parietal region. Although not central to our hypotheses, we have also included a visual cortex region as a quality check for fNIRS signal. Since all participants, including the speaker, viewed the same video stimuli, there may be some degree of synchrony in the visual cortex due to shared visual processing.

Preprocessing fNIRS data

Preprocessing and ISC calculations were completed for the two tasks: (1) the story listening task, where the storyteller is speaking and the participants are passively listening, and (2) the empathic accuracy task, where the storyteller and participants both rate the storyteller's affect during storytelling. Preprocessing and calculating pairwise correlations from the raw NIRS data were done in the AnalyzIR toolbox in MATLAB (Santosa et al., 2018). Preprocessing included checking and correcting stimulus marking, truncation of the time series to task-related data, and validation of signal-to-noise ratios across channels and participants.

Calculating Neural Synchrony with Intersubject Correlation (ISC)

Neural synchrony between speakers and listeners was calculated as the pairwise temporal intersubject correlation (ISC) between the speaker and each of her listeners. For each task, correlations between brain activity, as measured by fNIRS, were calculated across all participants; after data quality exclusions this resulted in 69 (usable data for story listening task) or 71 (usable data for emotion rating task) participants each paired with the storyteller. This pairwise ISC was calculated using the hyperscan module in the AnalyzIR toolbox (Santosa et al., 2018). This module uses autoregressive prewhitening and robust regression to find the correlation between two NIRS time courses. Based on guidelines in the literature, a model order of P=10 was chosen for prewhitening (Santosa et al., 2017). Autoregressive prewhitening reduces the serially correlated nature of NIRS data and minimizes confounding signals produced by systemic physiology (such as heart rate and respiration) and motion artifacts, by producing an "innovations" model of the time course data containing only independent information at each time point (Barker et al., 2013). Performing pairwise robust regressions down-weights outliers remaining from motion artifacts (Santosa et al., 2017). These methods improve control of Type I errors and replace the identification, removal and interpolation of motion artifacts used in older fNIRS preprocessing pipelines (Pfeifer et al., 2018; Yücel et al., 2017). Using the hyperscan module of the AnalyzIR toolbox, Pearson correlations were calculated for symmetrical (e.g., speaker left TPJ – listener left TPJ) pairs of ROIs in each speaker-listener pair across the length of the story.

Statistical Analyses

We then used this ISC measure to predict two outcome measures for the listeners: (1) empathic accuracy (EA) and (2) factual accuracy of story retelling (FA). We constructed a linear regression model for each ROI (i.e., $EA/FA \sim \beta 1 * ISC_{ROI} + error$). We also explored interactions between neural synchrony and the compassion training condition (i.e., $EA/FA \sim \beta 1 * ISC_{ROI} + \beta 2 * Condition + \beta 3 * (ISC_{ROI} * Condition) + error$).

Of the twelve brain regions represented in the whole-head fNIRS montage, seven regions of interest (ROIs), representing mentalizing, self-relevance processing and visual processing, are included in the preregistered analyses for this paper. As described above, we focused on mentalizing and self-relevance processing ROIs because synchrony of these psychological processes are hypothesized to support successful interpersonal communication. We included a visual processing ROI as a quality check for synchrony during exposure to the same audiovisual stimuli. We calculate ISC values for symmetric, matched pairs of ROIs, including the MPFC, DMPFC, right and left temporoparietal junctions (TPJs), right and left temporal regions and the visual cortex, between the speaker and her listeners (i.e. speaker's left TPJ vs. listener's left TPJ). To control for multiple comparisons, results were FDR corrected at $\alpha = 0.05$ using the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995).

Results

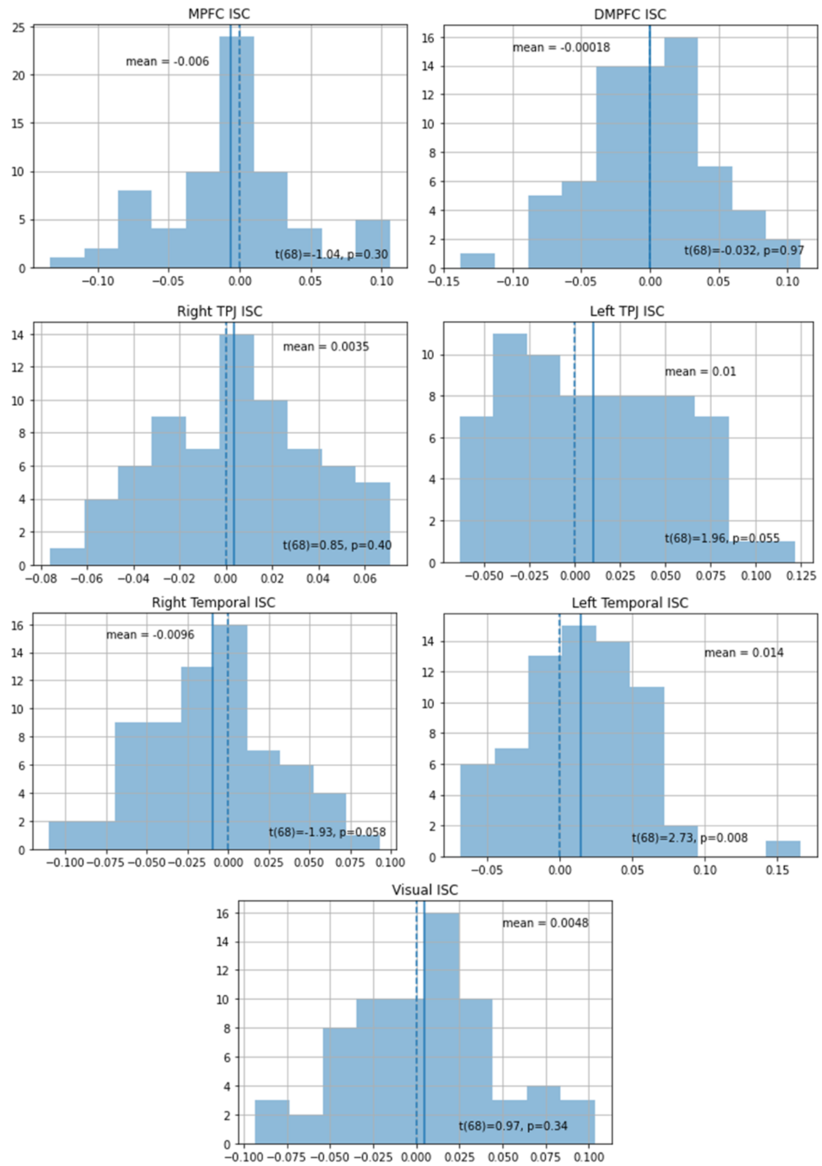
First, we examined the distribution of ISC values in each of our preregistered ROIs – MPFC, DMPFC, left and right TPJs, and visual cortex, as well as exploratory left and right temporal regions – in both the story listening (Figure 2.1) and emotion rating tasks (Figure 2.2). In the story listening task (N=69), across all regions the range of ISC values is from -0.171 to 0.165, indicating very small correlations between the speaker and listeners' neural activity in any region. One-sample t-tests in each region indicate where ISC differs significantly from zero. ISC in the left temporal region across all participants is significantly positive ($t=2.73$, $p = 0.008$). Removing one participant in the left temporal ROI data, with an outlier ISC value of 0.165, still produces significant ISC ($t=2.51$, $p = 0.014$). ISC in the left TPJ ($t=1.96$, $p=0.055$) and right temporal ($t=-1.93$, $p=0.058$) regions are marginally greater than and less than zero, respectively.

In the emotion rating task (N=71), the range of ISC values across all regions is from -0.151 to 0.149; as in the story listening task data, this indicates very small correlations between individuals' neural activity in any region. The left TPJ ($t=1.99$, $p =$

0.051), visual cortex ($t=1.95$, $p = 0.056$) and DMPFC ($t=1.82$, $p =0.073$) show marginally significant differences from zero in ISC. The visual region was included in the design as a quality check for our fNIRS signal, since viewing the same audiovisual stimuli should produce similar visual processing activity in any video viewer. These results give us some confidence that our fNIRS setup is accurately detecting brain activity.

Figure 2.1

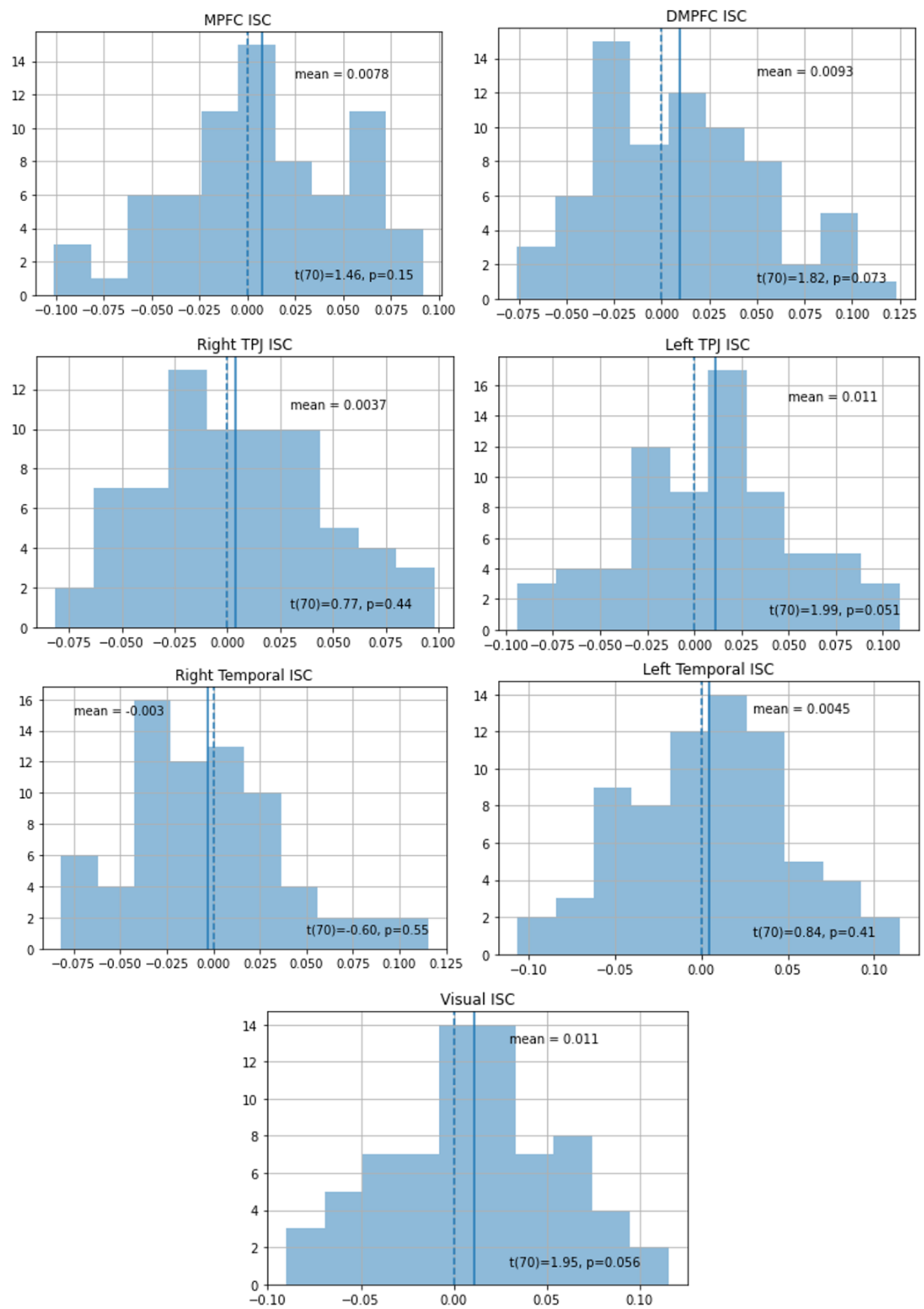
Distributions of ISC in each ROI in the story listening task



Note. Histograms of ISC in preregistered, symmetrical ROIs in the Story Listening task. The left temporal region shows significant positive ISC (t(68)=2.73, p=0.008). The left TPJ (t(68)=1.96, p=0.055) and right temporal (t(68)= -1.93, p=0.058) regions show marginal ISC. Dotted lines indicate zero ISC (x-axis); solid lines indicate mean ISC in the region.

Figure 2.2

Distributions of ISC in each ROI in the Emotion Rating task



Note. Histograms of ISC in preregistered, symmetrical ROIs in the Emotion Rating task. The left TPJ (t(70)=1.99, p=0.051), visual cortex (t(70)=1.95, p=0.056) and DMPFC (t(70)=1.82, p=0.073) show marginally significant ISC. Dotted lines indicate zero ISC (x-axis); solid lines indicate mean ISC in the region.

With the knowledge that some, but not all, of our preregistered regions show significant or marginally significant ISC, we turn to address the hypothesized relationships between ISC and behavioral outcomes, which focus on variability across individuals, rather than average levels of ISC overall. We predicted the accuracy of the listener's (1) understanding of the storyteller's emotional states during storytelling (empathic accuracy, EA) and (2) recall of factual information from the story (factual accuracy, FA) during two tasks (1) story listening, where the speaker is speaking and each listener is listening and (2) emotion rating, where the speaker and listeners rated the speaker's emotions during the story.

Predicting Empathic Accuracy when the speaker is speaking and the listener is listening

When listeners first heard a story, lower ISC between the storyteller and listener in the left TPJ predicts the listener's ability to accurately identify the storyteller's emotional states ($t(67) = -2.90$, $p_{corr} = 0.035$). An exploratory interaction analysis examining the effect of the compassion training versus control conditions also found a significant main effect of ISC in the left TPJ ($t(65) = -2.90$, $p_{corr} = 0.036$). Results for ISC in the remaining preregistered ROIs – MPFC, DMPFC, left and right temporal regions, right TPJ and visual cortex – were all non-significant (see Table 2.1). These results in the left TPJ, where greater speaker-listener ISC predicts decreased accuracy in emotion rating, are contrary to the original hypothesis of a positive relationship between neural synchrony and empathic accuracy.

Table 2.1

Predicting empathic accuracy by ROI in the story listening task

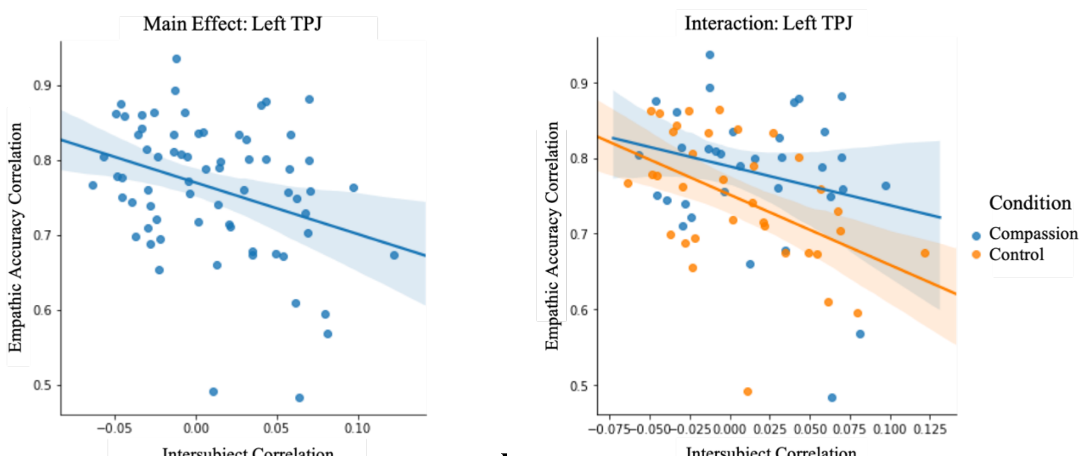
ROI	Main Effect Model			Interaction Model		
	β (SE)	**95% CI**	**t (p_{corr})**	**β (SE)**	**95% CI**	**t (p_{corr})**
MPFC						
ISC	0.10 (0.23)	(-0.36, 0.56)	0.45 (0.88)	0.19 (0.35)	(-0.51, 0.89)	0.55 (0.68)
Condition				0.034 (0.02)	(-0.01, 0.078)	1.58 (0.15)
Cond*ISC				-0.18 (0.46)	(-1.10, 0.74)	-0.39 (0.96)
DMPFC						
ISC	-0.073 (0.24)	(-0.56, 0.41)	-0.30 (0.88)	-0.45 (0.32)	(-1.09, 0.20)	-1.39 (0.59)
Condition				0.036 (0.021)	(-0.006, 0.078)	1.71 (0.15)
Cond*ISC				0.78 (0.47)	(-0.16, 1.72)	1.66 (0.72)
rTPJ						
ISC	-0.25 (0.32)	(-0.89, 0.39)	-0.78 (0.77)	0.40 (0.58)	(-0.76, 1.56)	0.70 (0.68)
Condition				0.039 (0.022)	(-0.005, 0.082)	1.77 (0.15)
Cond*ISC				-0.84 (0.70)	(-2.23, 0.55)	-1.21 (0.75)
lTPJ						
ISC	-0.69 (0.24)	(-1.16,-0.21)	-2.90* (0.035)	-0.93 (0.32)	(-1.57, -0.29)	-2.90* (0.036)
Condition				0.037 (0.021)	(-0.004, 0.079)	1.81 (0.15)
Cond*ISC				0.41 (0.47)	(-0.52, 1.34)	0.89 (0.75)
rTemporal						
ISC	-0.04 (0.26)	(-0.57, 0.45)	-0.16 (0.88)	0.14 (0.36)	(-0.57, 0.85)	0.40 (0.69)
Condition				0.032 (0.022)	(-0.012, 0.076)	1.45 (0.15)
Cond*ISC				-0.42 (0.52)	(-1.46, 0.63)	-0.80 (0.75)
lTemporal						

ISC	-0.27 (0.26)	(-0.79, 0.25)	-1.04 (0.71)	-0.32 (0.38)	(-1.08, 0.43)	-0.85 (0.68)
Condition				0.04 (0.023)	(-0.003, 0.088)	1.86 (0.15)
Cond*ISC				-0.07 (0.52)	(-1.11, 0.97)	-0.13 (0.96)
Visual						
ISC	0.30 (0.26)	(-0.23, 0.83)	1.13 (0.71)	0.26 (0.34)	(-0.42, 0.93)	0.76 (0.68)
Condition				0.034 (0.22)	(-0.01, 0.077)	1.53 (0.15)
Cond*ISC				-0.029 (0.55)	(-1.12, 1.06)	-0.053 (0.96)

Note. All p values were corrected following the Benjamini-Hochberg procedure (** = p <0.01; * = p < 0.05; † = p <0.10, corrected).

Figure 2.3

Speaker speaking – listener listening ISC predicts decreased empathic accuracy



a. **b.**

Note. Main effects in a model that does not include the interaction (a; $t(67) = -2.90$, $p_{corr} = 0.035$) and main effects in a model accounting for the interaction with compassion condition (b; $t(65) = -2.90$, $p_{corr} = 0.036$) in the left TPJ show increased speaker – listener ISC during storytelling predicting decreased empathic accuracy.

Predicting Empathic Accuracy when both speaker and listener engage in emotion rating

After listening to the story once, listeners then heard the story a second time and simultaneously made a continuous rating of the speaker's emotional state during storytelling. Looking at all listeners together in the preregistered main effects models, there is no significant relationship between speaker-listener ISC during this emotion rating task and empathic accuracy in any hypothesized ROI. Exploratory interaction models, however, show a significant interaction between ISC and condition in the left temporal region ($t(67) = -3.06$, $p_{corr} = 0.022$), as well as a marginal interaction in the left TPJ ($t(67) = -2.51$, $p_{corr} = 0.051$). These results suggest that the naturalistic story listening of the control condition and the trained listening of the compassion condition may produce different relationships between neural ISC and empathic accuracy. Breaking down the interaction, we observed a positive relationship between ISC and empathic accuracy in control participants (see Table 2.2; Figure 2.4).

Table 2.2

Predicting empathic accuracy by ROI in the emotion rating task

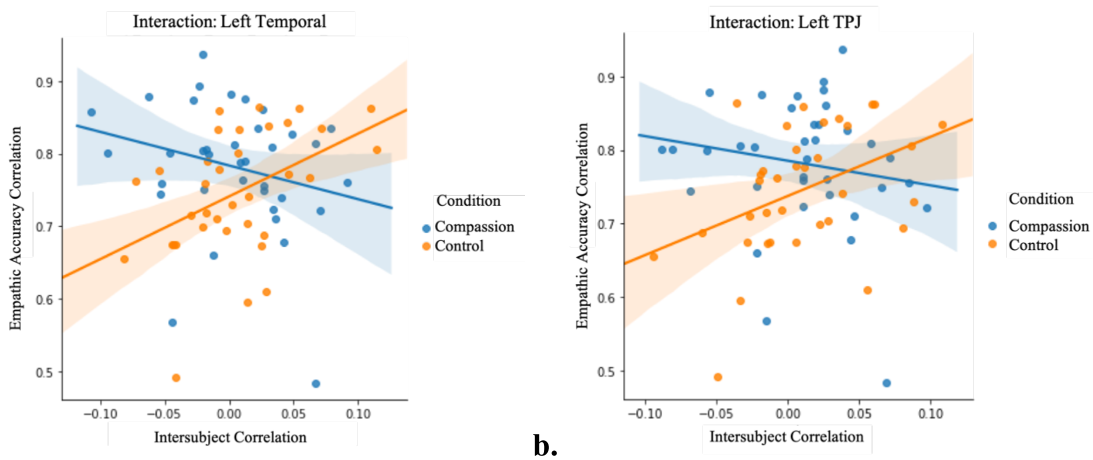
ROI	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	-0.16 (0.24)	(-0.64, 0.31)	-0.69 (0.58)	-0.39 (0.40)	(-1.20, 0.41)	-0.97 (0.39)
Condition				0.033 (0.021)	(-0.009, 0.076)	1.55 (0.15)
Cond*ISC				0.36 (0.49)	(-0.63, 1.35)	0.72 (0.55)
DMPFC						
ISC	-0.30 (0.25)	(-0.80, 0.19)	-1.24 (0.58)	-0.47 (0.37)	(-1.21, 0.26)	-1.28 (0.36)
Condition				0.03 (0.02)	(-0.013, 0.073)	1.39 (0.17)

Cond*ISC				0.38 (0.49)	(-0.60, 1.37)	0.78 (0.55)
rTPJ						
ISC	0.38 (0.26)	(-0.14, 0.89)	1.47 (0.58)	0.72 (0.36)	(0.001, 1.43)	1.99 (0.12)
Condition				0.044 (0.021)	(0.002, 0.086)	2.11† (0.089)
Cond*ISC				-0.52 (0.51)	(-1.54, 0.50)	-1.02 (0.55)
lTPJ						
ISC	0.23 (0.24)	(-0.25, 0.70)	0.94 (0.58)	0.80 (0.33)	(0.16, 1.45)	2.47† (0.056)
Condition				0.048 (0.021)	(0.007, 0.089)	2.33† (0.089)
Cond*ISC				-1.14 (0.45)	(-2.05, -0.23)	-2.51† (0.051)
rTemporal						
ISC	0.15 (0.26)	(-0.35, 0.66)	0.61 (0.58)	0.29 (0.38)	(-0.46, 1.04)	0.77 (0.44)
Condition				0.039 (0.021)	(-0.004, 0.082)	1.83 (0.10)
Cond*ISC				-0.11 (0.51)	(-1.14, 0.91)	-0.22 (0.82)
lTemporal						
ISC	0.16 (0.24)	(-0.31, 0.63)	0.68 (0.58)	0.87 (0.32)	(0.24, 1.50)	2.74† (0.055)
Condition				0.043 (0.02)	(0.003, 0.08)	2.15† (0.089)
Cond*ISC				-1.33 (0.44)	(-2.20, -0.46)	-3.06* (0.022)
Visual						
ISC	0.13 (0.24)	(-0.34, 0.60)	0.56 (0.58)	0.41 (0.40)	(-0.039, 1.21)	1.03 (0.39)
Condition				0.041 (0.022)	(-0.002, 0.084)	1.88 (0.10)
Cond*ISC				-0.42 (0.49)	(-1.40, 0.56)	-0.87 (0.55)

Note. All p values were corrected following the Benjamini-Hochberg procedure (** = $p < 0.01$; * = $p < 0.05$; † = $p < 0.10$).

Figure 2.4

Speaker - listener emotion rating ISC predicting empathic accuracy



a. **b.**

Note. The left temporal (a; $t(67) = -3.06$, $p_{corr} = 0.022$) and left TPJ (b; $t(67) = -2.51$, $p_{corr} = 0.051$) show significant and marginally significant interactions between control and compassion conditions.

In both (a) the left temporal ($t(67) = -3.06$, $p_{corr} = 0.022$) and (b) left TPJ regions ($t(67) = -2.51$, $p_{corr} = 0.051$), we observe an interaction, such that greater speaker-listener ISC is associated with more empathic accuracy for people in the control condition (left temporal: $t(33)=2.91$, $p = 0.006$; left TPJ: $t(33)=2.62$, $p = 0.013$), but not the compassion condition (left temporal: $t(34)=-1.48$, $p = 0.15$; left TPJ: $t(34)=-1.00$, $p = 0.32$).

Predicting Factual Accuracy when the speaker is speaking and the listener is listening

When listeners first heard the story, there was no significant relationship between speaker-listener ISC and factual accuracy in any region of interest. Likewise, interaction models show no main effects of ISC or condition and no interactions in any ROI (see Table 2.3).

Table 2.3

Predicting factual accuracy by ROI in the story listening task

ROI	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	4.33 (17.23)	(-30.07, 38.73)	0.25 (0.88)	-11.39 (26.70)	(-64.70, 41.93)	-0.43 (0.86)
Condition				0.49 (1.66)	(-2.83, 3.82)	0.30 (0.99)
Cond*ISC				27.15 (35.24)	(-43.22, 97.52)	0.77 (0.67)
DMPFC						
ISC	-5.93 (18.13)	(-42.12, 30.25)	-0.33 (0.88)	-8.60 (25.11)	(-58.76, 41.55)	-0.34 (0.86)
Condition				0.36 (1.66)	(-2.95, 3.66)	0.22 (0.99)
Cond*ISC				5.52 (36.91)	(-68.19, 79.22)	0.15 (0.88)
rTPJ						
ISC	6.08 (24.31)	(-42.44, 54.60)	0.25 (0.88)	-49.59 (44.31)	(-138.08, 38.91)	-1.12 (0.86)
Condition				-0.016 (1.66)	(-3.34, 3.31)	-0.01 (0.99)
Cond*ISC				81.23 (53.14)	(-24.90, 187.35)	1.53 (0.67)
lTPJ						
ISC	-8.69 (18.83)	(-46.27, 28.89)	-0.46 (0.88)	-15.56 (26.40)	(-68.27, 37.16)	-0.59 (0.86)
Condition				0.27 (1.71)	(-3.14, 3.68)	0.16 (0.99)
Cond*ISC				13.59 (38.39)	(-63.09, 90.28)	0.35 (0.85)
rTemporal						
ISC	3.88 (19.76)	(-35.55, 43.32)	0.20 (0.88)	-10.66 (27.27)	(-65.13, 43.81)	-0.39 (0.86)
Condition				0.63 (1.69)	(-2.75, 4.01)	0.37 (0.99)
Cond*ISC				31.13 (40.04)	(-48.83, 111.08)	0.78 (0.67)
lTemporal						
ISC	-2.94 (19.59)	(-42.05, 36.17)	-0.15 (0.88)	-18.99 (29.35)	(-77.61, 39.61)	-0.65 (0.86)

Condition				0.012 (1.76)	(-3.51, 3.53)	0.007 (0.99)
Cond*ISC				28.72 (40.36)	(-51.87, 109.32)	0.71 (0.67)
Visual						
ISC	9.43 (20.01)	(-30.51, 49.36)	0.47 (0.88)	-3.92 (25.96)	(-55.77, 47.93)	-0.15 (0.88)
Condition				0.042 (1.68)	(-3.31, 3.39)	0.025 (0.99)
Cond*ISC				33.75 (41.89)	(-49.92, 117.43)	0.81 (0.67)

Note. No region in either set of models shows main or interaction effects predicting factual accuracy during story retelling.

Predicting Factual Accuracy when both speaker and listener engage in emotion rating

When the speaker and listeners are rating the speaker's emotional state, there are no primary mentalizing or self-relevance regions of interest which show a main effect of ISC on factual accuracy. In the interaction models, there are no significant main effects of ISC or condition. There is, however, a significant interaction in the right temporal region ($t(66) = -2.87$, $p_{corr} = 0.039$; see Table 2.4). This crossover interaction indicates that the effect of ISC depends on the participants' condition; greater ISC in compassion training participants predicts less factual accuracy ($t(33) = -3.23$, $p = 0.003$), while there is no relationship between ISC and factual accuracy in control participants ($t(33) = 1.01$, $p = 0.32$).

Table 2.4

Predicting factual accuracy by ROI in the emotion rating task

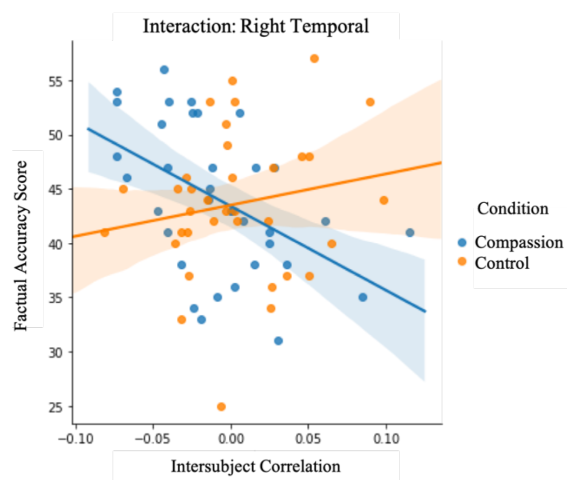
ROI	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	-3.27 (17.95)	(-39.09, 32.55)	-0.18 (0.99)	3.29 (31.15)	(-58.91, 65.49)	0.92 (0.92)
Condition				0.50 (1.66)	(-2.82, 3.81)	0.30 (0.95)
Cond*ISC				-9.76 (38.40)	(-86.42, 66.90)	0.80 (0.80)
DMPFC						
ISC	29.50 (18.34)	(-7.10, 66.10)	1.61 (0.53)	3.57 (27.67)	(-51.67, 58.81)	0.13 (0.92)
Condition				0.24 (1.63)	(-3.02, 3.50)	0.15 (0.95)
Cond*ISC				48.48 (37.16)	(-25.72, 122.68)	1.31 (0.34)
rTPJ						
ISC	-15.59 (19.61)	(-54.73, 23.54)	-0.80 (0.60)	17.57 (27.61)	(-37.56, 72.70)	0.64 (0.74)
Condition				0.49 (1.62)	(-2.74, 3.72)	0.30 (0.95)
Cond*ISC				-66.75 (39.44)	(-145.49, 11.99)	-1.69 (0.33)
lTPJ						
ISC	17.81 (17.94)	(-18.00, 53.61)	0.99 (0.68)	25.09 (26.01)	(-26.84, 77.02)	0.97 (0.59)
Condition				0.56 (1.67)	(-2.76, 3.89)	0.34 (0.95)
Cond*ISC				-14.32 (36.38)	(-86.95, 58.30)	-0.39 (0.80)
rTemporal						
ISC	-27.59 (19.08)	(-65.67, 10.48)	-1.45 (0.53)	28.65 (26.88)	(-25.01, 82.31)	1.07 (0.59)
Condition				-0.010 (1.54)	(-3.17, 2.97)	-0.065 (0.95)
Cond*ISC				-106.02 (36.96)	(-178.81, -32.23)	-2.87* (0.039)
lTemporal						
ISC	19.14 (17.49)	(-15.76, 54.05)	1.09 (0.57)	33.63 (25.61)	(-2.65, 3.82)	1.31 (0.59)

Condition				0.58 (1.62)	(-17.51, 84.77)	0.36 (0.95)
Cond*ISC				-27.42 (35.38)	(-98.05, 43.21)	-0.78 (0.62)
Visual						
ISC	-0.27 (17.74)	(-35.67, 35.12)	-0.015 (0.99)	32.76 (30.49)	(-28.13, 93.64)	1.07 (0.59)
Condition				0.97 (1.66)	(-2.35, 4.29)	0.58 (0.95)
Cond*ISC				-50.06 (37.51)	(-124.96, 24.83)	-1.34 (0.34)

Note. All p values were corrected following the Benjamini-Hochberg procedure (** = p <0.01; * = p < 0.05; † = p <0.10).

Figure 2.5

Speaker - listener emotion rating ISC predicting factual accuracy



Note. There is a significant interaction between control and compassion conditions in the right temporal region. The main effect of ISC is significant for the compassion condition (t(33) = -3.23, p = 0.003), but not the control condition (t(33) = 1.01, p = 0.32).

Exploratory Analyses

We ran one set of exploratory analyses, as well as repeating the main study analyses with the deoxyhemoglobin (HbR) data. First, three additional regions not part of our pre-registered mentalizing and self-relevance systems – the left and right temporal regions and the visual cortex – were used as predictors in linear regressions to predict empathic and factual accuracy. The deoxyhemoglobin (HbR) results from the preregistered, symmetric regions, are included in Appendix A; results from the symmetric, oxyhemoglobin (HbO) ISC data in the bilateral temporal and visual ROIs are included here.

The left and right temporal regions were included due to their adjacency to the left and right TPJ regions. Without a method of normalizing channel location across participants, inclusion of these regions helps to account for cap placement differences across participants that might result in channels included in one region being positioned over another region. Paralleling the findings in each ROI separately, combining the temporal and TPJ channels into a single ROI shows that speaker – listener synchrony in this left temporoparietal ROI significantly predicts empathic accuracy for control participants ($t(31)=3.73$, $p < 0.001$) but not compassion participants ($t(32)= -1.699$. $p=.099$). We also included the visual cortex as a quality check for ISC signal, but did not expect the visual cortex ISC to be predictive of either empathic of factual accuracy. Indeed, while the visual cortex does show marginally significant ISC in the emotion rating task ($t(70)=1.95$, $p=0.056$), it is not predictive of either empathic or factual accuracy in either the emotion rating (Empathic accuracy: $t(69)=0.56$, $p=0.58$; Factual accuracy: $t(68)=-0.015$, $p=0.99$) or story listening tasks (Empathic accuracy: $t(67)=1.13$, $p=0.26$; Factual accuracy: $t(67)=0.47$, $p=0.64$).

Discussion

The main goal of this paper is to test whether the synchrony between the speaker and her listeners is predictive of listeners' ability to understand the speaker's emotional states (empathic accuracy; EA) and remember the story (factual accuracy; FA). Our regions of interest constitute areas of the brain involved in mentalizing about the thoughts and emotions of others (primary regions of interest: the left and right TPJs and the DMPFC; secondary/ exploratory regions of interest included adjacent portions of the left and right temporal cortex) or involved in the self-relevance judgments and autobiographical memory (the MPFC). We hypothesized that greater ISC in these regions would be associated with greater empathic accuracy and greater factual accuracy, but found only weak support for this idea. We found the that neural synchrony in the left temporal and temporoparietal regions was related to empathic accuracy, but the nature of the relationship depended on the task each person was performing and the psychological context preceding the task.

When the storyteller and listeners were both engaged in the emotion rating task (i.e., listening to the same story and rating the speaker's emotional state), greater synchrony in the left temporal and (marginally) left TPJ regions between the speaker and her listeners predicts increased empathic accuracy for participants in the control condition. This follows the hypothesized relationship, where more similar mentalizing activity between communicators correlates with more similar understanding of the storyteller's emotions. Here, the storyteller and listeners are exposed to the same stimuli, the original storytelling video, and perform the same psychological task of tracking and rating the storyteller's emotions. While the storyteller was watching and rating herself, she was instructed not to recall how the events of the story made her feel at the time they occurred, but rather to judge how she felt while telling the story. This framing requires perspective taking in a way that may mimic mentalizing about another person. Given the task framing, synchrony in the left temporal and left TPJ regions suggests that the speaker may have engaged in thinking about her past emotional states, just as her listeners were thinking about her emotional states.

Although the study hypotheses related to the interaction between neural synchrony and the compassion condition are not of primary interest in this dissertation, including the interaction models allow us to separate the effect of ISC in the control group of interest from that of the compassion group to better understand psychological processes which naturally occur in an audience of listeners. Here we observed that ISC was associated with greater empathic accuracy only in the control condition. Research on the effects of mindfulness and compassion training suggests that these types of interventions do not always improve empathic accuracy. While there is some evidence that limited training increases individual's ability to understand other's emotional states based on facial expressions (Tan et al., 2014), others have found no relationship between mindfulness training and empathic accuracy (Lim et al., 2015; Ridderinkhof et al., 2017) or that the effect is moderated by personality traits (Winning & Boag, 2015). In our data, the fact that ISC was only related to empathic accuracy for control participants suggests that compassion training may engage alternative means of understanding another person, beyond synchrony in mentalizing or self-related processing regions. For example, it might encourage more cognitive deliberation and a more distanced perspective.

In contrast to the findings in the emotion rating task, when the speaker and her listeners engaged in different behaviors in the story listening task, we observed a surprising reversal of the predicted effects. Specifically, when the listeners first heard the story, in the story listening task, less speaker-listener synchrony in the left TPJ predicts increased empathic accuracy. This finding is counter to the hypothesis that more synchrony in mentalizing regions would benefit the communication and understanding of emotion. This may be due to the nature of the two tasks in the study. In the emotion rating task, the storyteller and her listeners are all thinking about the speaker's emotion. In the story listening task, however, the storyteller is producing the narrative while the listeners are processing the narrative. Aside from the differing neural activity related to speech production and comprehension, the storyteller may be mentalizing about her audience, attempting to craft an engaging, clear and memorable story, while the listeners are encoding new narrative information, or perhaps the speaker is thinking more about what others will think of her. The inverse relationship between neural synchrony in the left TPJ and empathic accuracy may indicate the asymmetry of these psychological processes. It is also worth noting that the listeners were only instructed to attend to the storyteller's emotions in the second task and that the second task was their second hearing of the story, so the task design of the emotion rating task itself may have provoked greater mentalizing in listeners.

Across both the story listening and emotion rating tasks, neural synchrony did not predict factual accuracy during the listeners' story retellings. In one prior fMRI study of speaker-listener synchrony, synchrony in regions of the brain including the dorsolateral and medial prefrontal cortices predicted factual recall (Stephens et al., 2010). A combined fNIRS-fMRI replication of the storytelling task from Stephens and colleagues does not report running the factual accuracy analysis from the original study (Y. Liu et al., 2017). The evidence for neural synchrony as a predictor of the communication of factual information may not be particularly robust, but it certainly bears further investigation.

We did observe one crossover interaction between synchrony and condition in the right temporal region during the emotion rating task. This indicates significant differences in the prediction of factual accuracy in control versus compassion training participants. We first note that it is possible that this activity might result from channel overlap between the right temporal region and right TPJ, as we see in the left temporal/left TPJ overlap predicting empathic accuracy, or it could be the result of real activity in the right temporal region during emotion rating. If channel overlap between regions were behind this finding, we might expect a trend toward a significant main effect or interaction in the right TPJ during the same task. In the absence of that, it is less clear whether mentalizing activity from participants in the control condition is related to remembering the facts of a story.

Alternatively, we look to possible explanations for right temporal region activity. A Neurosynth meta-analysis search based on channel midpoints across the six right temporal channels suggests several functional attributions with posterior probabilities greater than 0.80 (Yarkoni, n.d.) in the right temporal region. "Action observation," "video"/"video clips" and "audiovisual stimuli" are probable associations in two channels, as are "voice," "speaker," and "vocal" in two different channels. The terms "emotional information," "memory load" and "language comprehension" each appear in one channel in the right temporal ROI, with some overlap with video viewing and auditory processing functions in those channels. As our analysis is based on mean ISC across all channels in the region, it is not possible to pinpoint a specific channel driving the crossover effect. Emotional information processing, memory load and language comprehension are all involved in story listening when the listener is preparing to retell the story, but it is not necessarily clear why there would be a difference in activity between control and compassion training conditions. One possibility is the way that participants were thinking about retelling the story differed according to the condition. Although the evidence is mixed for the effect of contemplative practices such as compassion training on empathic accuracy (Ridderinkhof et al., 2017; Tan et al., 2014; Winning & Boag, 2015), studies have found effects of mindfulness training on the processing of emotional information and working memory. There is some support for the idea that compassion training may modulate the activity of brain regions involved in emotional information processing and memory, including the right temporal region. Taken together, it seems possible that the crossover effect between neural synchrony and participant condition in the right temporal region when predicting factual accuracy could be task-driven, although there are multiple possible explanations for the observed effect and further research is needed.

Across all regions, we found that ISC is significantly or marginally significantly different from zero for several regions in each task, suggesting that our tasks generated speaker-listener ISC, which was detectable through fNIRS. During the story listening task, where the speaker was telling her story and the listeners were watching her video for the first time, significant ISC in the left temporal region and marginally significant ISC in the right temporal region may indicate overlapping activations in speech production and comprehension (Silbert et al., 2014). In the emotion rating task, where both the speaker and the listeners were re-watching the story video and making continuous ratings of the speaker's emotions, synchrony in the visual cortex may index the primary visual processing of the video stimulus. The lack of visual cortex ISC in the story listening task may be due to differences in attention to the video for the speaker – who is watching herself while trying to maintain a coherent and fluent narrative – and the passively watching listeners.

Some findings may be attributed to methodological issues with fNIRS. Although we initially included the visual cortex ROI as a quality check, it turned out that we had poor accessibility of the primary visual cortex to the fNIRS signal; as such we do not make strong interpretations of the results related to visual cortex. Likewise, issues with channel placement across participants as well as the spatial specificity of fNIRS mean that neighboring regions of interest in the fNIRS montage may overlap in the analysis. The directionally consistent evidence in the left TPJ and left temporal ROIs when predicting empathic accuracy during emotion rating may be the result of this overlap, as well as indicative of effects related to real activation synchrony in those regions.

fNIRS is an evolving technology and, as such, there are a number of limitations due to the continual development of best practices in the field. For example, measurement of extracerebral hemodynamics – the blood flow in the scalp, which adds noise to the hemodynamic signal from the brain – is becoming a standard practice, so this noise can be excluded in preprocessing (L. Gagnon et al., 2014; Yücel et al., 2021). Our current fNIRS system, however, is not equipped with the short-separation channels which allow for such shallow hemodynamic measurements. Likewise, measurement of physiological data, such as end-tidal CO_2, is increasingly seen as important for fNIRS measurement of speech production tasks, as lower CO_2 pressure when breathing during speech produces changes in cerebral hemodynamics independent of cognitive tasks (Pinti et al., 2019; Scholkmann et al., 2013).

In addition to technological developments in instrumentation and updates to our understanding of how tasks contribute to contamination in the hemodynamic signal, fNIRS remains a difficult technology to use across ethnically diverse adult populations. Unobstructed contact between the light sources and detectors in a NIRS system determines much of the signal quality. Any material that prevents skin-to-optode contact, like hair follicles, or absorbs light before it can reach cortical tissue, such as melanin in skin or hair, increases the burden for participants during cap setup and the difficulty of obtaining useable fNIRS signal for analysis. Due to these challenges, it has been standard practice for many labs to enquire about hair texture and color in recruitment, and to recruit participants who will be easier to set up in the fNIRS cap; this practice is also common in electroencephalography (EEG) studies, where contact between electrodes and the scalp determines signal quality (Webb et al., 2022). While fNIRS studies can and have been done in populations of African (Lloyd-Fox et al., 2017; Lloyd-Fox et al., 2019) and Asian (Perdue et al., 2019) descent, they are often designed to optimize data acquisition. Some studies have focused on development in infant and toddler populations, who have thinner skulls than adults and therefore pass light more readily into the cortex (Aslin et al., 2015); some studies concentrate on prefrontal regions, where hair occlusion is not a concern, or they may minimize the number of recording channels and ask participants to style or braid their hair before the study appointment to facilitate cap setup. Some of these adaptations, such as hair styling, can be used in adult populations, but the challenges of running a study with a large montage, such as our 102-channel design, in an adult population are still an area in need of improvement. We are in the process of active conversation in the field (Webb et al., 2022), among engineers designing systems and analysis software as well as the social scientists and researchers aiming to recruit study participants as diverse as the population. However, the lack of racial diversity in our sample is a significant limitation in interpreting our findings. As an evolving technology, fNIRS is still a promising method for lower cost, portable, wearable neuroimaging.

Regardless of method, future studies of speaker-listener synchrony in storytelling should extend these findings to investigate the relationship between synchrony and memory for stories, seeking to replicate the findings of Stephens and colleagues (2010). Another next step for storytelling research is to include additional hallmarks of successful communication, including the transmission of stories beyond the original storyteller.

This study provides limited support for the idea that neural synchrony between a speaker and her listeners indexes how accurately listeners understand the storyteller's emotions, and how they change over the course of the story. Similarity in mentalizing activity, particularly in the left temporoparietal regions, suggests that the speaker and her listeners engage in similar processes to understand the thoughts and perspectives of the person who is receiving or telling the story. This finding suggests that processing social information through mentalizing about the thoughts of communication partners potentially leads to greater success in communicating at least the emotional dimension of a story. It is not clear, however, if synchrony between communication partners extends to other forms of successful communication, including the spread of stories. Understanding if neural synchrony predicts story transmission, or uptake of stories by listeners who hear the story secondhand, will provide insight into the role of shared brain activity in storytelling.

CHAPTER 3

Audience synchrony is related to successful communication in story retelling

Abstract

Sharing personal stories is a ubiquitous social behavior. Here, we test the idea that successful communication involves developing a shared sense of personal reality with others, or seeing the world in a similar way to others. Using functional near infrared spectroscopy (fNIRS), we investigate the role of neural synchrony in brain regions involved in social and self-relevance processing among audience members in successful story retelling. We measure communication success in terms of three key dimensions: the perceived authenticity of the retold version of the story, the speaker's overall appeal, and the listener's experience of the story. Specifically, after each listener in the study (n=39, female) heard an autobiographical story and then retold it as though the experience happened to them, the retold stories were rated by an independent group of subsequent listeners (n=1,097, female) on the three dimensions of successful communication. Story retellers whose brain activity was closest to the group average when initially hearing the story were perceived as more authentic by subsequent listeners, had greater appeal overall, and produced a better listener experience, operationalized as enjoyment of the story and likelihood to share the story with others. Being perceived as authentic when retelling a story to a new audience may reflect normative patterns of response to stories.

Introduction

Storytelling is perhaps the most enduring form of communication. As we see in Chapter 2, there is some evidence that neural synchrony between a storyteller and her listeners, in regions associated with mentalizing about the thoughts of others, influences how accurately listeners understand the storyteller's emotions. Additional impact of a story is derived from whether it spreads to new audiences when people retell the story to others. In this study, we focus on perceptions of retellers' authenticity, their overall appeal, and the subsequent listener's experience as metrics for communication effectiveness, and examine the neural processes during initial story listening as a predictor of these outcomes.

We argue that successful communication involves developing a shared sense of personal reality with others. In the case of retelling an autobiographical narrative, this could be achieved by aligning one's own sense of self, or worldview, in relation to the story with other potential audience members. Indeed, theories of embodied social cognition argue that people come to understand others minds through simulation (Semin & Cacioppo, 2008). Recent findings also suggest that people who see the world similarly show correlated neural responses to video-based stories (i.e., neural homophily), and are more likely to become friends (Parkinson et al., 2018). Through a similar mechanism, successful communication may stem from self-representations related to the story that align with other individuals' experiences of the story.

We operationalize successful communication in three ways: (1) speakers are perceived as authentic (hereafter 'perceived authenticity'), (2) listeners find the speaker appealing and (3) the listeners report a positive overall experience of the story. Each of these factors incorporates multiple items. Perceived authenticity encompasses the believability and trustworthiness of a speaker, as well as the realism of their story retelling. The speaker's appeal is based on the listener's perception of her personality and story delivery, encompassing her enthusiasm, likability and similarity to the listener. Finally, the listener's overall experience captures both their enjoyment during story listening and their likelihood of sharing the story with someone else.

Perceived authenticity differs from psychological accounts of personal authenticity, which emphasize self-knowledge and intentional behavior in daily life (Grabowski & Rasmussen, 2014; Guttman et al., 2008). Instead, we focus on the how story retellers simulate personal experience when they adopt and retell another speaker's story. Though it may seem akin to acting, adopting another's autobiographical story and sharing it as your own is not uncommon in everyday social interaction (A. S. Brown et al., 2015, 2020); for example, by recounting a friend's experience of meeting a celebrity as though the event happened to you.

In these cases, the appeal of a speaker may depend upon their enthusiasm for the story, as well as how likeable they seem and how similar the listener perceives them to be. Enthusiasm in verbal communication, defined by vocal tone, expressiveness and energy, is associated with better learning outcomes for students both in person (Keller et al., 2016) and in virtual learning environments (Liew et al., 2020). Different levels of enthusiasm across retellers may indicate both varying degrees to which the story resonated with the retellers when they first heard it and to what extent the retellers considered how the story may be received by their subsequent listeners (E. B. Falk et al., 2012). In persuasive narratives, liking for and perceived similarity to characters predict story engagement (Hoeken et al., 2016), and the persuasiveness of narrative messages (M. Kim et al., 2016). The listener's overall experience of the story, captured as enjoyment, may also influence their later success at story retelling (Green et al., 2004). Taken together, we use these factors to index the success of communication during storytelling between speakers and listeners.

To operationalize the shared experience or shared sense of personal reality that we argue characterizes successful communication, we focus on intersubject correlation (ISC) between the brains of different individuals (Hasson et al., 2004; Hasson, Furman, et al., 2008). Cultural stimuli (e.g. stories) have been shown to elicit shared responses across listeners in brain regions implicated in both self-relevance processing and understanding others' mental states, i.e., mentalizing (Hasson et al., 2009).

People who interpret narrative events similarly show more correlated brain patterns than those who have an alternative interpretation (Yeshurun et al., 2017), as do individuals who are friends (Parkinson et al., 2018) and individuals who are the most popular in their friendship group (Baek et al., 2022). In other words, more similar perspectives are associated with greater synchrony in brain response, which may in turn be an underlying ingredient in being perceived as authentic. We focused on two brain systems, in particular, that are involved in processing self-relevance and social information about others' mental states.

Brain systems that track the relevance of information to the individual include the medial prefrontal cortex (MPFC) and other cortical midline structures (Denny et al., 2012; Lieberman et al., 2019). ISC between one individual and other audience members, also known as one-to-rest ISC, in the MPFC may index the degree to which that potential reteller's self-relevance experience of the story mirrors group consensus. Thus, we expected a positive relationship between one-to-rest ISC within the MPFC and how subsequent listeners perceive the authenticity of that reteller's version of the story. More similar recruitment of self-relevance processing may indicate a common experience of the relevance of the story, which leads subsequent listeners who hear a retold version of the story to also find self-relevance in the story.

A related possibility is that successful communication could be the product of more accurately taking the perspective of others and mirroring group norms within brain systems implicated in mentalizing. Mentalizing most commonly recruits regions of dorsomedial prefrontal cortex (DMPFC) and bilateral temporal parietal junction (TPJ), among other regions (Koster-Hale et al., 2017; Saxe, 2010). A positive relationship between one-to-rest ISC in mentalizing-related regions and subsequent perceived authenticity would suggest that individuals who track the group mean in terms of social considerations during story listening are later perceived as more authentic. More similar recruitment of mentalizing regions may represent a shared perception of how to retell a story so others will perceive it as authentic, appealing and enjoyable.

In contrast with the recruitment of self-related and mentalizing processes, if retelling successfully requires only a memory for story events and not synchrony of self-relevant or social thought between the reteller and others, correlated neural activity in these brain systems would not be expected to be predictive of successful communication

The Current Study

In sum, in line with previous research (Y. Liu et al., 2017; Stephens et al., 2010), we expected to see significant ISC across story retellers in brain systems implicated in self-relevance and social information processing. In addition, we substantially extend prior work by testing the idea that the extent to which an individual's brain synchronizes with others may predict an individual's ability to retell a story in a manner that others perceive as authentic and appealing. In the current investigation, we test these possibilities using functional near-infrared spectroscopy (fNIRS) neuroimaging. We also examine neural predictors of objective accuracy of their retellings of the same story. In line with the view that shared cultural norms arise from shared neural representations of narratives, we hypothesized that:

Hypotheses

H1: Listeners will show significant synchrony in brain regions associated with self-relevance processing and mentalizing while listening to the same personal narrative.

H2: Listeners who show the most convergence with others' brain responses within mentalizing and self-relevance processing regions of interest (when they hear the story) will later be more successful communicators when retelling the narratives themselves.

H3: Among listeners, those who show the most convergence with others' brain responses within mentalizing and self-relevance processing regions of interest will later show increased factual accuracy in story retelling.

Methods

Participants

One speaker participant (female) recorded a video of herself telling an autobiographical narrative as part of a pilot study. The video of this story (270s duration) was used in the present study as the stimulus for the storytelling task for the group of listener/reteller participants (n=39, female; M_{age}=36.6, SD_{age}=16.3). An original autobiographical narrative and the storytelling task were also collected for male participants (n=20); this seed story, however, lacked verbal fluency and structural clarity. Participants' difficulty in retelling the story mean that these data are not included in the current analysis. Three female listener/reteller participants in the present study were excluded from analysis due to global issues with poor fNIRS data quality; analyses are based on the remaining 36 participants, where individual channels within participants were excluded as necessary due to poor data quality. For the second part of the storytelling task, additional participants (n=1,097, female; see Appendix B for age distribution) were recruited on Amazon's Mechanical Turk. Each of these participants listened to one retelling of the story from a listener/reteller participant, and rated that story on an 8-item scale of successful communication, including factors for perceived authenticity of the speaker, speaker appeal and overall experience.

Storytelling Task

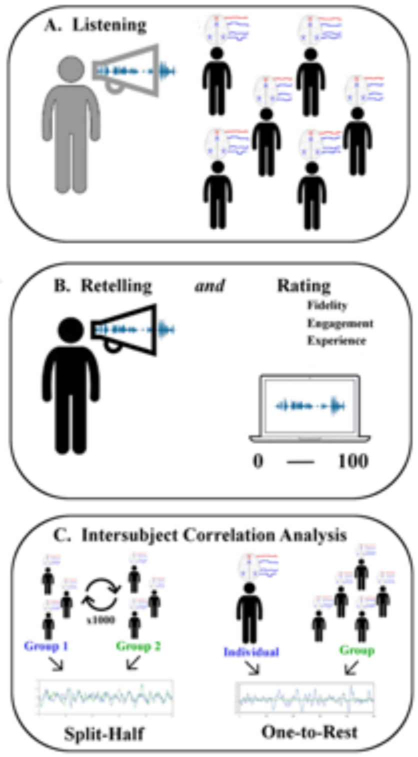
The storytelling task developed for this study consisted of two sections. In one section ("Retelling"), participants underwent fNIRS recording while first watching a video of the speaker's autobiographical story and then recording a video of themselves retelling the story in the first-person, as though the events of the story happened to them. In the other section of the storytelling task ("Telling"), also while undergoing fNIRS recording, participants were asked to video record themselves telling an autobiographical narrative from their own lives. Participants were given a set of instructions, including a goal story length of five to seven minutes, and asked to choose from among four story prompts prior to telling their story. Analysis of the Telling task is not included in this paper. The order of the Retelling and Telling sections was counterbalanced across participants.

Story Evaluation Task

Each of the 36 retold versions of the story, plus the version from the original storyteller, were presented for the evaluation of the overall success of communication, operationalized in terms of the speaker's perceived authenticity, the speaker's appeal and the listener's experience. At least 25 Amazon MTurk workers (M=29.6, SD=3.04) listened to an audio-only version of each retold story and rated it on a sliding scale from zero to 100 on eight items: (1) the believability of the story, (2) realism that the story events happened to the speaker, the speaker's (3) trustworthiness, (4) enthusiasm, and (5) likeability, (6) similarity of the speaker to the listener, (7) the listener's enjoyment of the story and (8) their likelihood of retelling the story to others. In an exploratory factor analysis, we identified three sub-factors of successful communication corresponding to (1) perceived authenticity (combining believability, realism and the speaker's trustworthiness), (2) speaker appeal (enthusiasm, likeability and similarity) and (3) listener experience (enjoyment and their likelihood to retell the story).

Figure 3.1

Study Design



Note. A. Story retellers first watched a video of an original storyteller telling an autobiographical narrative, while undergoing fNIRS. B. After listening, each listener retold the story in the first person, as though the events of the story had happened to them. Amazon MTurk workers then listened to each of the 36 retellings, plus the original story, and rated them on three dimensions of authenticity. C. Two forms of intersubject correlation analysis were conducted; split-half ISC was used to confirm correlation across listeners during story listening, while one-to-rest ISC allowed for individual-level comparison between brain activity during listening and ratings of perceived authenticity of the retold story.

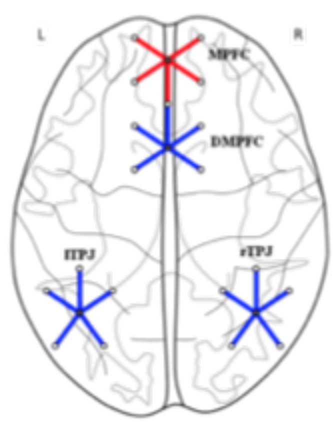
fNIRS Probe Design and Data Collection

Data were recorded on a TechEn CW6 32 x 32 channel fNIRS system located at the Center for Human Growth and Development at the University of Michigan (TechEN, Milford, MA). The layout of the probe was designed to capture the four regions of interest (ROIs): the medial prefrontal cortex (MPFC), the dorsomedial prefrontal cortex

(DMPFC) and the bilateral temporoparietal junctions (bilateral TPJs). These ROIs were chosen due to their involvement in self-relevance processes (MPFC) or mentalizing about others thoughts and beliefs (bilateral TPJs, DMPFC). Each ROI was covered by a radial five-channel pattern with six optodes (one source and five detectors; see Figure 3.2), based on previous fNIRS probe designs (Cutini et al., 2012); detectors were anchored on the international 10-20 points (Homan et al., 1987). The overall probe design consisted of four sources and 19 detectors, with a single detector shared between the DMPFC and MPFC; source-detector pairs formed a total of 20 channels. See Appendix B for further information about data collection procedures and preprocessing.

Figure 3.2

fNIRS Probe Design



Note. Black dots represent sources; white circles represent detectors. The probe consisted of 20 channels divided over four regions of interest. Red channels comprise the MPFC region, which is implicated in self-relevance. Blue channels comprise the DMPFC and bilateral TPJs which, taken together, form the mentalizing system.

Intersubject Correlation Analyses

Intersubject correlation (ISC) measures the synchrony in neural activity over a time course between two groups of participants (split-half) or between one participant and the group (one-to-rest) (Hasson et al., 2004). For continuous time-series neuroimaging data, like those obtained with fNIRS, ISC preserves the detail of the data and allows for direct correlations between neural and behavioral data (Chen et al., 2017; Hasson & Honey, 2012). For complex and "messy" naturalistic stimuli like movies and stories, ISC allows for the direct comparison of neural responses to the same stimuli between individuals (Hasson, Furman, et al., 2008; Schmälzle et al., 2015; Stephens et al., 2010).

In the split-half ISC analysis, data are iteratively randomly split into two groups, with data for each channel and ROI averaged within each group, before calculating between groups ISC. For robustness, these data were split and averaged 1000 times; the ISC reported is the mean ISC from all iterations across ROIs over the 270 second duration of the story.

For the one-to-rest ISC analysis, the time series of activity in each participant in each ROI (averaged across channels within the ROI) is compared to the mean of the activity for the rest of the participants. This approach allows for computation of an individual's similarity to the group response, and correlation of that similarity (ISC) to behavioral measures, like perceived authenticity of a story reteller. In all analyses, we report ISC based on the relative change in oxygenated hemoglobin (HbO) concentration, due to its increased robustness over deoxygenated hemoglobin (HbR), and its correlation with the BOLD signal measured in fMRI (Cui et al., 2010; Y. Liu et al., 2017).

Successful communication in story retelling

Factor analysis of the eight-item measure of successful communication revealed three subscales representing (1) perceived authenticity (combining believability, realism and the speaker's trustworthiness), (2) speaker appeal (speaker's enthusiasm, likeability and similarity to the listener) and (3) listener experience (enjoyment and their likelihood to retell the story). These three subscales cumulatively explain 71% of the variance in ratings across story retellers. The three factor scores for each speaker were calculated; on a scale of 0 to 100, perceived authenticity ranged from 20.74 to 81.01 (M=64.78), speaker appeal ranged from 16.06 to 60.74 (M=41.8) and listener experience ranged from 7.06 to 58.81 (M=35.95). The three subscales are highly correlated (see Appendix B), but captured distinct dimensions within our factor analysis.

Behavioral accuracy in story retelling

To determine the degree of accuracy in story retelling, we coded the original story into discrete factual elements, producing a 50-item rubric of facts that could be recalled in retelling (see Appendix B). Each participant's retelling of the original story was then coded by a member of the research team for these 50 facts. Participants were given credit for facts if they were recalled at all, regardless of the order of recall. Actual recall scores for the 36 participants ranged from 10 to 39 out of 50, with a mean score of 30.33 (SD=6.81).

Neural predictors of successful communication and accuracy in story retelling

Linear regressions predicting the communication outcomes of interest (i.e., perceived authenticity, speaker appeal, listener experience and factual accuracy) from one-to-rest ISC using system-level data followed the model: Outcome ~ $\beta 1$*Self_ROI$_{ISC}$ + $\beta 2$*Mentalizing_ROI$_{ISC}$+ error. Additional models treating each ROI separately (i.e., Outcome ~ $\beta 1$*MPFC$_{ISC}$ + $\beta 2$*DMPFC$_{ISC}$ + $\beta 3$*RTPJ$_{ISC}$ + $\beta 4$*LTPJ$_{ISC}$+ error) can be found in Appendix B.

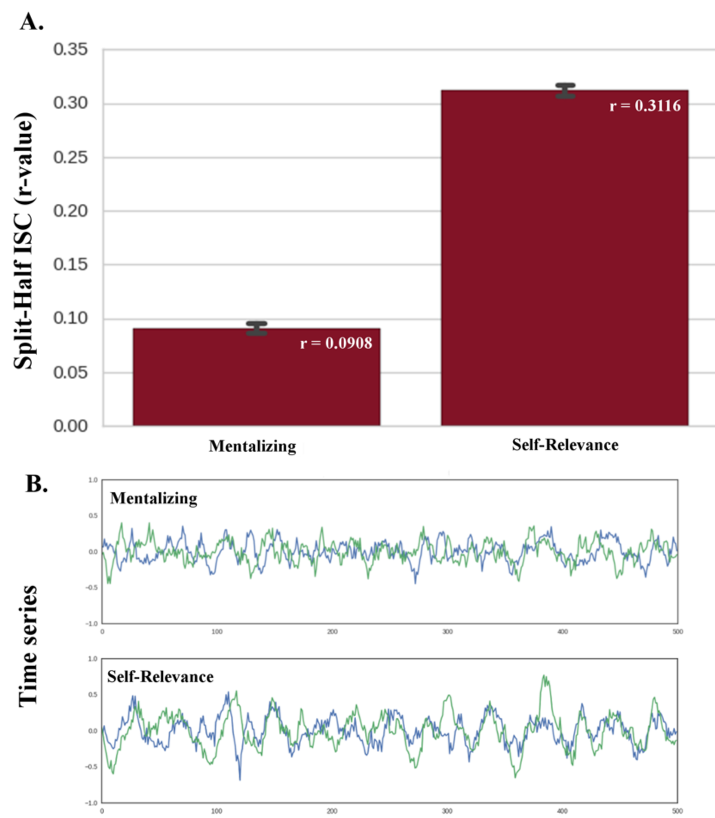
Results

Shared representations of the story indexed by Split-Half ISC in each ROI

We first tested whether there was significant intersubject correlation across the fNIRS channels, within each of our two systems of interest. To do so, we aggregated each five-channel group into an ROI. The ROIs were then further aggregated by systems; the DMPFC, right and left TPJs form the mentalizing system, while the MPFC represents a self-relevance system (see Appendix B for details). The split-half ISC across these systems was calculated as outlined in the Methods section; participants were randomized into two groups and the mean of all channels was calculated for each participant in each system, before calculating ISC between the two groups. This process is bootstrapped 1000 times to produce stable split-half mean ISC results. Figure 3.3 shows the correlation between groups of subjects in each ROI. Randomized, bootstrapped split-half ISC shows significant ISC across all listeners in the self-relevance ROI (MPFC: $r = 0.3116$, 95% CI: (0.3066, 0.3165)) and in the combined mentalizing ROI (DMPFC and TPJs: $r = 0.0908$, 95% CI: (0.0863, 0.0953)). Figure 3.4 shows the distribution of bootstrapped split-half ISC values in the self-relevance and mentalizing systems.

Figure 3.3

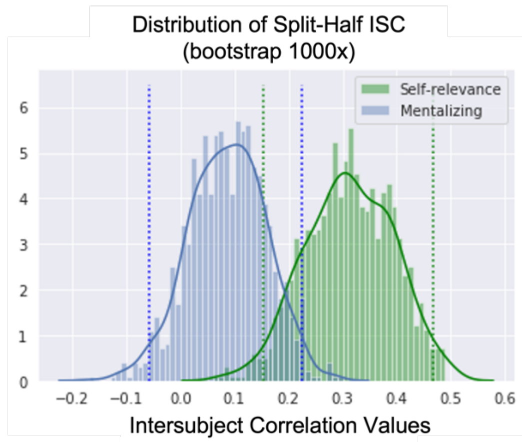
Split-half ISC by system



Note. A. Average intersubject correlation between halves of the data bootstrapped across 1000 iterations. These data indicate that ISC exists among listeners while they are listening to the story, and that synchrony is strongest in the self-relevance ROI (i.e., MPFC). Data for mentalizing regions (i.e., DMPFC, bilateral TPJs) show a mean ISC of 0.0908, while self-relevance ROI (i.e., MPFC) data show a mean ISC of 0.3116. B. Traces of the average split-half ISC for the self-relevance and mentalizing systems over the duration of the story (270 s).

Figure 3.4

Distributions of split-half ISC by system



Note. Distributions of ISC values in the self-relevance (i.e. MPFC ROI) and combined mentalizing (i.e. DMPFC, bilateral TPJ ROIs) systems. Dotted lines represent 95% confidence intervals for each distribution.

ISC predicts successful communication, through perceived authenticity, speaker appeal and listener experience

We next examined the relationship between one-to-rest ISC in each brain system of interest as participants were initially exposed to the story they later re-told, and independent ratings of the story reteller's success. Successful communication was operationalized with ratings by independent coders that capture the reteller's perceived authenticity, appeal and the subsequent listener's (i.e., independent coder's) experience of the story. We examined separate models predicting each of these sub-factors from activity within MPFC and the mentalizing system (i.e., Perceived Authenticity ~ $\beta 1 * MPFC_{ISC} + \beta 2 * mentalizing_{ISC}$ + error). We tested for and excluded outliers, defined as values in the residualized models outside three standard deviations from the mean. One data point in the model predicting perceived authenticity was identified and excluded as an outlier; the regression table and plot for this model with the full data set are included in Appendix B, but the conclusions do not substantively change with or without inclusion of this outlier. Results from models treating each region of interest separately, as well as the correlations between each ROI, are included in Appendix B.

Activity within the self-relevance ROI (i.e., MPFC) predicted successful communication in terms of perceived authenticity ($t(29)=2.375$; $p=0.024$), speaker appeal ($t(30)=2.572$; $p=0.015$), and listener experience ($t(30)=2.136$; $p=0.041$). One-to-rest ISC of activity in the mentalizing system (i.e. combined DMPFC and bilateral TPJs) was not significantly related to any of the three factors (perceived authenticity ($t(29)=-0.727$; $p=0.473$), speaker appeal ($t(30)=-1.808$; $p=0.081$), and listener experience ($t(30)=-1.449$; $p=0.158$).

Table 3.1

Perceived Authenticity~ $\beta 1 * MPFC_{ISC} + \beta 2 * mentalizing_{ISC} + error$

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	63.165	2.098	30.101	<2e-16
MPFC	0.435	34.499	14.524	2.375	0.024*
mentalizing	-0.133	-12.703	17.473	-0.727	0.473

Note. Predicting the authenticity of the speaker in retelling by ROI (df=29). Measure combines believability, realism and the speaker's trustworthiness ratings from MTurk ratings of story retellings (** = $p < 0.01$; * = $p < 0.05$; † = $p < 0.10$). Note: results including one outlier are in Appendix B, and suggest similar conclusions.

Table 3.2

*Speaker Appeal ~ β1*MPFC*$_{ISC}$ *+ β2*mentalizing*$_{ISC}$ *+ error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	39.554	2.148	18.416	<2e-16
MPFC	0.451	38.512	14.976	2.572	0.015*
mentalizing	-0.317	-31.947	17.671	-1.808	0.081†

Note. Predicting the engagement between the speaker and listener in retelling by ROI (df=30). Measure combines enthusiasm, likeability and similarity ratings from MTurk ratings of story retellings (** = p <0.01; * = p < 0.05; † = p <0.10).

Table 3.3

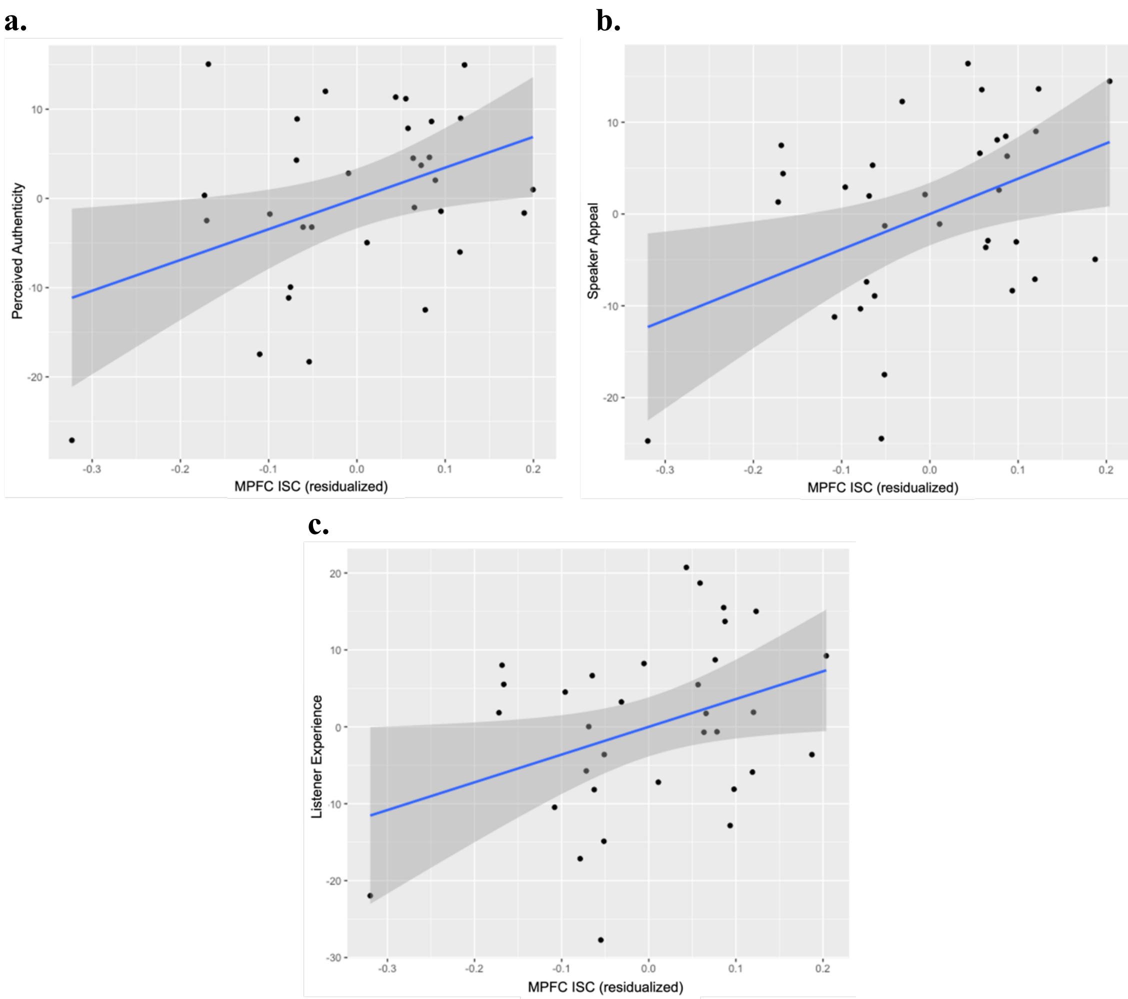
*Listener Experience ~ β1*MPFC*$_{ISC}$ *+ β2*mentalizing*$_{ISC}$ *+ error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	33.710	2.422	13.918	1.24e-14
MPFC	0.387	36.075	16.889	2.136	0.041*
mentalizing	-0.263	-28.871	19.928	-1.449	0.158

Note. Predicting the listener's experience of the story in retelling by ROI (df=30). Measure combines enjoyment and likelihood of retelling the story ratings from MTurk ratings of story retellings (** = p <0.01; * = p < 0.05; † = p <0.10).

Figure 3.5

One-to-Rest ISC and successful communication



Note. As an individual's synchrony with the rest of the group increases, so does their subsequent listeners' judgments of (a) perceived authenticity, (b) speaker appeal, and (c) listener experience.

One-to-Rest ISC in MPFC and story retelling accuracy

To determine whether neural responding in self-relevance and/or mentalizing regions of interest predicts the accuracy with which listeners retell the speaker's narrative, we examined the degree to which each participant's neural activity mirrored the rest of the listener group's neural activity. We then correlated this one-to-rest ISC with each individual's total accuracy in retelling the story. Within the MPFC ROI, we did not find a significant relationship between one-to-rest ISC and accuracy, although the data trend toward a positive relationship (t(30)=1.828; p=0.078).

Table 3.4

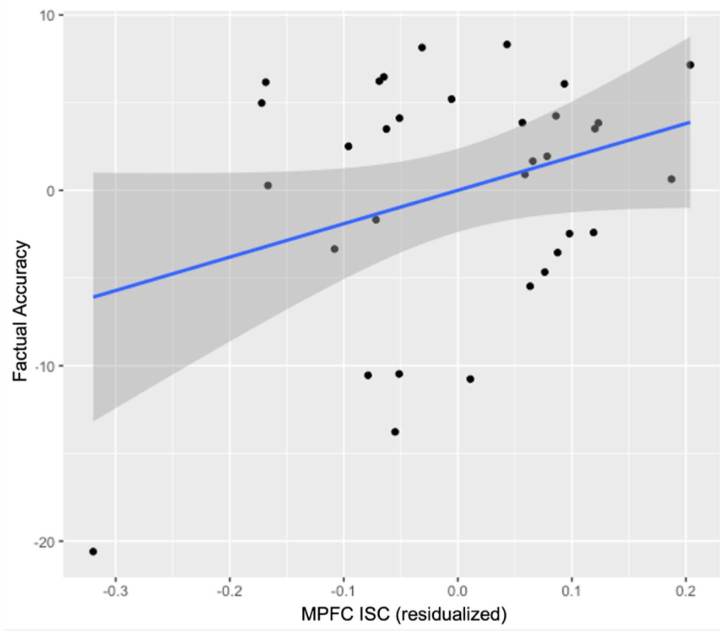
Factual Accuracy ~ $\beta 1 * MPFC_{ISC} + \beta 2 * mentalizing_{ISC} + error$

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	28.586	1.494	19.135	<2e-16
MPFC	0.339	19.039	10.417	1.828	0.078†
mentalizing	-0.057	-3.795	12.291	-0.309	0.759

Note. Predicting factual accuracy in retelling, by ROI (df=30). (** = p <0.01; * = p < 0.05; † = p <0.10).

Figure 3.6

One-to-rest ISC and factual accuracy



Note. One-to-Rest ISC and individual retelling accuracy ($t(30)=1.828$; $ß = 0.339$; $p=0.078$). As an individual's synchrony with the rest of the group increases, their factual accuracy when retelling the original speaker's personal narrative, in the first person, marginally increases.

Discussion

We investigated the brain processes associated with being successful in story retelling. Consistent with past research on audience engagement with narratives (Y. Liu et al., 2017; Stephens et al., 2010), we found significant intersubject correlation among a group of listeners exposed to an autobiographical narrative, particularly within the medial prefrontal cortex (MPFC), a brain region implicated in processing the self-relevance of information. Extending this research, we also explored whether people whose brains experience stories in a way that is similar to others are more successful as story retellers—specifically, we tested individual differences in the degree to which each participant's brain activity was in sync with the rest of the group when listening to a story. This one-to-rest ISC within the MPFC during listening was significantly related to how subsequent, independent listeners rated the authenticity of the retellers' stories, the speaker's appeal and also produced a more positive listener experience. Together, these findings are consistent with a model in which the degree to which an individual is successful in communicating is a function of their tendency to reflect broader group norms and values around the self-relevant elements of a narrative.

From the split-half ISC analysis, we found that listeners as a group showed significant synchrony in both the MPFC region of interest, targeted for its role in self-relevance processes (Denny et al., 2012; Lieberman et al., 2019; Schmitz & Johnson, 2007), and to a lesser degree within mentalizing regions of interest, including DMPFC and the bilateral TPJs (Saxe, 2010; Scholz et al., 2009). These data add to a growing body of studies that show consistency across audiences in perceptions of complex, real world stimuli such as personal narratives, measured with both fMRI (Stephens et al., 2010) and fNIRS (Y. Liu et al., 2017). In addition to audience synchrony during autobiographical narratives, significant ISC in audiences has been found during persuasive political speeches (Schmälzle et al., 2015), within groups of individuals primed to perceive fictional story events in a similar way (Yeshurun et al., 2017) and during movie viewing among people who share friendship ties (Parkinson et al., 2018). In the context of listening to a personal narrative, which the individual plans to later retell, we observed particularly robust effects within the MPFC. This is consistent with the idea that narrative stimuli can collectively engage self-relevance processes within groups of participants, even when the original events have not happened to any of them. That said, the degree to which each individual participant showed ISC with the rest of the group varied. As such, we explored the possibility that this variation might have consequences for the way in which they retold the story, and hence the degree to which others would perceive each participant as authentic in the retelling.

Within the same self-relevance ROI, individual listeners who showed greater synchrony with the group as a whole were later rated as more highly in all three dimensions of successful communication. The first factor, perceived authenticity, encompasses the believability and trustworthiness of the storyteller, and the realism of the events in the retold story. The second factor, speaker appeal, encompasses the reteller's enthusiasm, likeability and the listener's perception of their similarity. Finally, the third factor, listener experience, represents the subsequent listener's enjoyment and their willingness to retell the story to others.

Listeners whose initial self-focused neural responses to the original story were more similar to the average response of all other listeners were then perceived as more authentic, more appealing and were judged to produce a more positive listener experience when they retold the story to a broader group of subsequent listeners whose brains were never scanned. Successful retellers' more representative neural responses may allow them to retell the story in a way which provokes a more similar neural response in their subsequent listeners. Neural synchrony predicts the closeness of social relationships in a friendship network, suggesting that individuals who are friends process stimuli in similar ways (Parkinson et al., 2018). Regardless of social closeness, more popular individuals –

those who are named as a friend by many other individuals in the network – show neural activity that is more similar to the average activity across the network, as well as more similar to other popular individuals (Baek et al., 2022). In the context of this study, the reteller's similarity to the group average neural activity may index a broader representation of normative understanding and evaluation of story events. Effectively, when what is self-relevant to the reteller represents events and interpretations which are self-relevant to their subsequent listeners, they seem more authentic and connect with their listeners more effectively when retelling the story. The accuracy of the retold story is not enough; even when information is factually accurate, if it does not conform to listeners' experience of and expectations about the world, listeners will not perceive the storyteller as authentic (Petraglia, 2009). This emphasizes the need for common understanding and shared expectations between a speaker and her listeners, which may be indexed by neural synchrony. Synchrony in activation of the MPFC among story retellers supports this account of successful communication.

More broadly, by showing that synchrony in brain regions that process self-relevance is associated with perceptions of authentically re-telling a story, we connect individual and interpersonal perspectives on authenticity. Individualistic approaches to authenticity typically focus on the psychological representation of one's true self during everyday interactions (Kernis & Goldman, 2006; Wood et al., 2008). In this view of authenticity, self-understanding forms the core of the individual's ability to behave authentically. In parallel, interpersonal perspectives on authenticity have focused on the how people appear to be genuine and true to who others believe them to be in social interactions (Newman & Smith, 2016). Listeners may be predisposed to perceive speakers as authentic. Social schemas which guide our evaluation of authenticity in others default to the judgment that others are generally morally good and truthful (Hicks et al., 2019). Research on the perceived authenticity of romantic partners (Wickham, 2013), political and organizational leaders (Zheng et al., 2020) and even strangers engaging in online communication (Tang et al., 2020) suggests that trait stability and consistent presentation of beliefs and values, in both face-to-face and online interactions, influences whether others perceive communication partners as authentic. Perceived authenticity predicts interpersonal relationship outcomes independent of attachment with parents, romantic partners or friends (Wickham et al., 2018). These results, connecting perceived authenticity in story retelling to self-relevance processing, highlight a potential intersection between individual and interpersonal perspectives on authenticity. If synchrony between brain regions implicated in understanding relevance of information to the self, rather than regions involved in mentalizing about the thoughts of others, is associated with being perceived as authentic then perceived authenticity may reflect a deeper synchrony in adapting the self to group norms, rather than merely understanding others' perspectives.

In addition to the role of the MPFC in identifying self-relevant stimuli, activity in the MPFC can also index other cognitive processes likely recruited during story listening and retelling. Prefrontal regions direct visual attention to stimuli; Song and colleagues (2021) found that dyadic ISC in the MPFC (and other regions of the default mode network) predicted viewers' self-reported attention during movie viewing. Greater activity in the MPFC during story listening, at the point when the story would be encoded into episodic memory, predicted increased recall of story facts in a group of listeners (Masís-Obando et al., 2022). This finding connects MPFC activity during memory encoding to story recall, but does not suggest that the synchrony of neural activity between individual listeners predicts factual accuracy.

As in Chapter 2, we investigated whether ISC in the self-relevance or mentalizing systems predicts the accuracy with which listeners remember and retell the story. We did not find a relationship between ISC in our key regions of interest and factual recall. This is inconsistent with one study of ISC during storytelling (Stephens et al., 2010), which suggests that speaker-listener ISC predicts factual accuracy during story recall, but an fNIRS replication of the same story listening task does not report results for the factual accuracy analysis (Y. Liu et al., 2017). Other studies, however, do support the finding that synchrony in broad terms predicts memory for facts; for instance, heart rate synchrony between speakers and listeners does predict memory for stories (P. Pérez et al., 2021). In contrast to, and extending these findings, the audience synchrony we report does not significantly correlate with the accuracy of listener's retellings of the story. Synchrony between communicators may be more important for story comprehension and memory (Chen et al., 2017), while synchrony among an audience of listeners may better represent the normative understanding necessary to retell a story authentically.

This study shows that synchrony among an audience of listeners, who listen to an autobiographical story then retell that story as though the events happened to them, predicts how subsequent, independent listeners rate the authenticity, speaker appeal and listener experience of retold stories. These findings support the suitability of fNIRS for measuring brain activity during complex, naturalistic communication (Y. Liu et al., 2017). Our results also add support to the literature that neural synchrony among an audience of listeners leads to successful communication (Schmälzle et al., 2015; Yeshurun et al., 2017). Substantially extending past research, we find that synchrony in self-relevance processes during listening predicts successful communication during subsequent story retelling, suggesting that a reteller's reflection of shared group norms and experiences may be one key element of successful communication.

CHAPTER 4

Shared preferences and audience synchrony in entertainment

Abstract

As we've seen in the past two chapters, sharing stories can promote shared neural activity in an audience of listeners. Audiences, however, are comprised of individuals who have different attitudes and preferences; these preferences may impact how each person understands a message and the degree to which their brain activity may be similar to other audience members. In this study, we examine whether the congruence between audience members' preferences and message content predicts neural synchrony in brain regions associated with mentalizing and self-relevance processing. These processes, which involve thinking about the thoughts of others or judging how relevant information is to the self, may be recruited when viewing and thinking about recommending content that varies in its self-relevance. We tested whether synchrony within an audience group who share preferences is greater than synchrony between individuals with different preferences, reflecting the similar ways they understand the messages. Recruiting individuals with preferences for different entertainment content – either sports events or theater performances – participants viewed promotional videos for both event types. Here we found that although we successfully manipulated congruence between the videos and participant preferences (i.e., participants reported stronger liking for message content that reflected their prior preferences), we did not observe greater synchrony between audience members with similar preferences, and congruence between content and preferences does not predict synchrony within audience groups. This suggests that, while

entertainment content appeals to people based on their self-reported preferences, audiences who share a preference for content do not necessarily show greater neural synchrony in mentalizing or self-relevance regions.

Introduction

Successful communication involves shared understanding between speakers and listeners, and among a group of listeners as they propagate a story to a new audience. In Chapter 2, we show that speaker-listener ISC in regions involved in mentalizing, particularly the left temporal and left TPJ regions, predicts the listeners' accuracy at understanding the speaker's emotions. This suggests that mentalizing similarly about the thoughts of a communication partner is related to more empathic accuracy. In Chapter 3, we show that ISC in self-relevance processing among an audience of listeners predicts successful communication when individuals retell a story. A normative understanding of the story, measured as similarity to the audience mean in the MPFC, was associated with retellers seeming more authentic, appealing and providing a better overall listener experience to their subsequent listeners. Taken together, these studies show that synchrony in brain regions involved in self-relevance processing and mentalizing about the thoughts of others predicts some components of successful communication, including the listener's accuracy in understanding the storyteller's emotions, and perceived authenticity of a reteller during story transmission.

In the current chapter, we turn from autobiographical stories to communicating entertainment content – promoting leisure activities, rather than personal narratives – to an audience. In particular, if neural synchrony is driven by similarity (Parkinson et al., 2018), it is possible that people for whom particular types of content are especially self and socially relevant might show more similar neural responses to one another. In the context of entertainment, individuals who are "fans" of certain content – such as sporting events or theater performances – may share neural mechanisms for self and social information processing when viewing their preferred content. In this study, therefore, we ask whether congruence between a listener's preference and message content is related to synchrony in self-relevance and mentalizing brain regions.

Neural synchrony in audiences occurs in a variety of contexts, including exposure to rhetorically strong messages (Schmälzle et al., 2015), shared experience (Kauppi et al., 2010), social closeness and shared attitudes (Parkinson et al., 2018), particularly to political messages. Audiences show greater ISC in response to strong arguments in political speeches (Schmälzle et al., 2015) and health messages (Imhof et al., 2020), suggesting that features inherent to messages can produce synchrony in general audiences, though these studies did not investigate the impact of prior attitudes to the message content. Individuals who hear the same music (Abrams et al., 2013) or watch the same movie (Kauppi et al., 2010) show synchrony in both lower-level auditory and visual processing regions, as well as higher-level cognitive regions.

People who are close or similar to one another also show greater synchrony. Romantic couples show neural synchrony during communication, while paired strangers do not (Kinreich et al., 2017). Network studies show that neural synchrony during movie viewing predicts friendship ties in a real-world social network (Parkinson et al., 2018) and that more popular individuals are more likely to show similar neural activity than less popular individuals in a network (Baek et al., 2022).

A number of studies have also examined synchrony within audiences based on political attitudes. Leong and colleagues (2020) found not only that ISC in the DMPFC was significantly different in politically liberal versus conservative participants during viewing of issue-based political videos, but also that the similarity between an individual's activity in the DMPFC and the mean ISC of all others who share their political attitudes predicts similar support for liberal or conservative positions. Divergent neural synchrony between liberal and conservative groups was most evident during political debate footage, rather than news clips presented with neutral wording (van Baar et al., 2021). Greater pairwise ISC between individuals who share political attitudes predicts the similarity of their attitudes toward the debates (van Baar et al., 2021). Using a "neural reference groups" approach, Dieffenbach and colleagues (2021) predicted an individual's political attitudes based on their neural similarity to mean ISC in audiences with known political attitudes.

Since political stimuli reliably produce different ISC based upon audience attitudes, it is possible that other identity-relevant attitudes or preferences could produce group-based synchrony across individuals' brains. In this study, we examine audience synchrony in two preference groups – sports and theater fans. Sports and theater events share a number of features but are also frequently dichotomized in research on leisure participation. Both event types are (usually) live, where fans attend in person and are co-present with others, and both events are open for individuals' participation at amateur levels while also enjoying spectatorship at the professional level (Conner, 2013). Both types of events also emphasize prior knowledge and event schemas as a way to understand and enjoy the events (Hallmann et al., 2017; Obaidalahe & Steils, 2018). Sports and theater are also heavily marketed to their target audiences (Han et al., 2016; Le et al., 2016), suggesting that exposure to promotional material for events is common place.

Although there is little evidence of changes in neural processing particular to fans of sports and theater, there are neural correlates of experience in both domains. Language processing offers some evidence that being a sports fan may change brain activity. Activity in the dorsal premotor cortex during comprehension of hockey action sentences is more similar between hockey players and hockey fans than for individuals with no experience playing or watching hockey (Beilock et al., 2008). Supporting the idea that playing a sport affects neural synchrony, dyads of college basketball players show significantly greater ISC during a cooperative drawing task than dyads of individuals with no experience in team sports (Li et al., 2020). In theater, professional Chinese opera actors show decreased resting state activity in brain regions related to speech and emotion processing (W. Zhang et al., 2018). The general scarcity of literature on neural adaptations as a result of training or spectatorship in sports or theater makes it difficult to draw conclusions about how brain activity may differ between different fan groups, but there is at least some research suggesting that participation, if not spectatorship, alters neural processing.

As in Chapters 2 and 3, in the current study we focus on ISC in self and social information processing brain regions. In the MPFC, synchrony within fan groups during viewing of congruent entertainment content may index finding similar moments self-relevant; this may be especially true for content matching the group's preference. In the mentalizing system regions, the DMPFC and bilateral TPJs, synchrony within fan groups may indicate thinking similar thinking about players' or characters' motives, or why or how others would value the content.

The Current Study

In this study, we investigated whether neural synchrony in mentalizing and self-relevance processing regions of the brain is greater across individuals with shared preferences, and further whether this is particularly true when they see entertainment content congruent with their preference than incongruent entertainment. We measured both behavioral ratings and neural synchrony via ISC during exposure to content that is congruent or incongruent with the participants' existing interests. Individuals who self-identified as sports or theater fans were exposed to promotional videos for both sports and theater events, creating both interest-congruent (e.g., sports fans watching sports promos) and interest-incongruent (e.g., sports fans watching theater promos) conditions.

Behavioral Hypotheses

H1a: Between sports and theater groups, fans have greater composite liking scores for congruent (preferred) content than incongruent content. Separately, we will verify that each fan group rates its congruent content more highly than the same content is rated by the other, incongruent fan group (i.e., sports fans' liking scores for sports events are greater than theater fans' liking for sports events).

H1b: Within each fan group, fans have greater composite liking for congruent over incongruent content (i.e., sports fans' liking scores for sports events are greater than their liking for theater events).

Neural Hypotheses

H2a: Between sports and theater groups, fans show greater ISC in self-relevance and/or mentalizing regions of interest for (1) all congruent content vs. all incongruent content, and (2) as a robustness check, between the congruent condition for one group and the incongruent condition for the other (i.e., sports fan's ISC during sports events are greater than theater fan's ISC during sports events).

H2b: Within each fan group, fans show greater ISC in self-relevance and/or mentalizing regions of interest for congruent over incongruent content (i.e., sports fans' ISC during sports events is greater than their ISC during theater events).

Methods

Participants

Participants (n=20, female, $M_{age} = 22.15$, $SD_{age} = 2.64$) were recruited based on their self-reported preference for viewing and attending theater or sports events. In order to recruit only those individuals with strong preferences for either theater or sports, rather than those who liked both event types, participants had both (1) a self-reported preference as "more of a theater fan" or "more of a sports fan," and (2) a score difference of at least 10 points out of a possible 30 in their composite liking scores for sports and theater events. Due to difficulties recruiting the targeted number of sports fans, the required score difference was lowered to 5 points, resulting in one sports fan participant with a score difference of 6. See the screening survey in Appendix C for details. Since normative engagement with sports and theater varies by gender (Bouchet et al., 2011; Chan & Goldthorpe, 2005; Gencer, 2015), we recruited only females. All participants completed the main study appointment procedures as outlined below.

The literature on intersubject correlation within and between groups of listeners is limited in both method and scope, consisting of mostly fMRI studies and studies which detect effects in brain regions unrelated to the hypotheses of this study. Although our n=20 sample size – n=11 theater fans and n=9 sports fans – is small, it is comparable to other small sample sizes in the ISC literature (Y. Liu et al., 2017; Schmälzle et al., 2015). Due to the relatively large number of observations across pairs of participants, a post-hoc power calculation shows that we can detect an effect size of d = 0.41 at 80% power, α =0.05 (Westfall, 2016).

Overview of procedures

Screening

Participants met general criteria for neuroimaging studies, plus hair color criteria related to fNIRS signal quality. Criteria were: right-handedness, English fluency, no history of stroke/neurological disorders/PTSD, no use of psychotropic medication in the previous 8 weeks, no admission to a psychiatric hospital in the past 12 months and hair color between medium brown and blonde/gray. Hair color selection is due to the technical limitations of the fNIRS system, which can experience signal loss in dark hair.

Participants were recruited through printed flyers and online through Experiments@Penn. A Qualtrics-based screening survey was used to categorize potential participants as sports or theater fans and confirm eligibility for fNIRS. The survey questions included all exclusion criteria, as well as the demographic and fan classification screening questions asked during norming for the video stimuli (see Appendix C for details on video norming). Participants were classified as sports or theater fans based on their total liking for three different events in each category; where there was less than a 10-point difference in total liking for sports and theater events (i.e., people are fans of both or neither), participants were not recruited.

Main study appointment

Upon arrival for the fNIRS recording, participants were introduced and consented to the study, measured for cap fit, then asked to complete pre-recording surveys. After these surveys, the fNIRS cap was fitted and the fNIRS signal was calibrated to ensure usable data. Participants then completed the *Theater-Sports Viewing Task*, watching and rating promotional videos for sports and theater events, which is the main focus of this chapter. Following these promotional videos, all participants then watched the first 10 minutes of their most preferred sports and theater events, and recorded a five-minute recommendation for each of those events (not the main focus of this chapter). Total fNIRS recording time was approximately 40 minutes. After the recommendation recording, the fNIRS cap was removed and participants completed post-task surveys. The session ended with a debrief about the purpose of the study and participants were compensated for their participation.

Theater-Sports Viewing Task

All participants watched six short (~90s) promotional videos in a randomized order; three for live theater events (comedy, drama, musical) and three for live sports events (basketball, football, soccer). The inclusion of multiple content subtypes for each category is an attempt to avoid case-category confounds and increase the chances of having events that each participant likes. After each video, they rated the event on a 5-point Likert scale for willingness to attend and recommend (*I would buy a ticket*; *I would attend if I was given a ticket*; *I would recommend to others*), as well as overall interest (*How interested would you be in seeing the first 10 minutes of this event?).* The current study analyzes only the data collected from this first set of short promotional videos.

After viewing and rating the promotional videos, participants watched a longer segment of their most liked event in each category (~10 min). This allowed the participants to have more material upon which to create a detailed recommendation, and allows for potential follow-up neural analyses that are not the focus of the current study. After viewing each longer segment, the participants recorded an approximately 5-minute recommendation video, describing the event, protagonists, actions they saw in the promotional video and longer segment, as well as their evaluations of whether and why they would like to attend the event.

Stimulus Materials

The stimuli consist of video footage from live professional sports and professional theater events, which are broken into two sets: the first set consists of short promotional videos of each event, while the second set shows longer (~10 minute) selections of continuous action from the same events.

Six short (~90s) promotional videos were constructed by the research team to a standardized script (see supplemental materials). Three videos feature professional live sporting events, in each of three categories: soccer, football, basketball. The other three videos show professional live stage plays, also in three categories: comedy, drama and musical theater. Each promotional video is built on the same script for voiceover narration, with information specific to the event added to minimize differences in affective content or engagement between the videos but allow them to accurately describe the event being promoted. The same male narrator is used for all six videos.

The second set of longer (~10 minute) videos were also constructed by the research team. All longer videos show the first 10 minutes of each event; all events were pre-selected to include specific actions (e.g., climax of a theatrical scene, scoring during a soccer game) and introduce multiple protagonists within the first 10 minutes. The purpose of these videos was to provide increased content to allow for greater detail in participants' recommendations for these events.

Video Norming

The videos were normed on Amazon's Mechanical Turk (N=40 MTurkers, female, M_{age}=23.33, SD_{age}=2.14; 28 White, 5 Asian or Pacific Islander, 3 African American, 3 Hispanic, 1 No Answer) along 11 dimensions, capturing visual and auditory qualities, arousal, engagement and desire to view the featured event. Each MTurk worker was categorized as a sports or theater fan based on their preference for attending sports and theater events. All six videos were shown, in fully random order, to each MTurk worker; after viewing each video, participants answered norming questions. The norming confirmed that sport and theatre fans perceived their congruent category videos (i.e., sport videos for sport fans; theatre videos for theatre fans) as equally compelling. Detailed information on video norming procedures and results is available in Appendix C. The current study analyzes only the data collected from this first set of short promotional videos.

fNIRS Probe Design and Data Collection

The fNIRS data were collected using NIRStar software from a NIRx NIRScout 32 x 32 system, currently located in the Communication Neuroscience Lab in the Richards Medical Research Laboratories building at the University of Pennsylvania. The fNIRS setup consists of 32 LED sources and 32 photodiode detectors in a flexible fabric cap, producing a 102-channel array recording at 3.84 Hz. This is the same montage as in Chapter 2 (see Appendix C), but the firing pattern of the sources is updated to allow for pairs of distant sources to fire simultaneously, which doubles the recording speed.

This montage covers medial and lateral areas of the prefrontal cortex, including the MPFC and DMPFC, and lateral parietal areas including the bilateral TPJs (see the supplemental materials for the montage diagram). Channels associated with each region of interest were determined by overlaying the template montage on a standard brain to produce MNI coordinates, and reconciling those MNI locations to a standard brain atlas (AAL2; Okamoto et al., 2009; Tsuzuki & Dan, 2014).

Prior to data collection, fNIRS signal was calibrated for each participant. When signal quality was poor, adjustments were made to the cap setup, including clearing hair from beneath optodes and placing an opaque cap over the fNIRS cap. The calibration was re-run a maximum of three times; for participants with lighter hair, good to excellent signal can usually be achieved across all channels in one to two calibrations. All participants in the current study showed good signal-to-noise ratios within two calibrations.

During data collection, one fNIRS raw data file was collected for each task. Five raw files were collected per participant: from (1) the viewing and rating task for the six short promo videos, (2) during viewing each of the two (theater and sports) 10-minute videos, and (3) during each of the two recommendation recordings.

Brain regions of interest

Given our hypotheses that shared preferences influence how individuals experience judgments of self-relevance and mentalizing about others' perspectives, two sets of brain regions are important for these analyses. Self-relevance processing is associated with activity in the medial prefrontal cortex (MPFC), among other regions; individuals show increased activity in the MPFC when they find information more self-relevant (Denny et al., 2012). Mentalizing about the thoughts of others – which is particularly relevant when considering how to recommend an event – recruits the dorsomedial prefrontal cortex (DMPFC), as well as the bilateral temporoparietal junctions (TPJs) (Saxe, 2010), among other regions. We will investigate ISC in self-relevance and mentalizing regions as markers of the neural similarity of self-relevance and mentalizing processes within groups who share a preference, and between groups with opposite preferences.

Analysis

fNIRS preprocessing

As in Chapter 2, preprocessing and ISC calculations for the fNIRS data were run using the AnalyzIR toolbox (Santosa et al., 2018). Preprocessing included checking and correcting stimulus markers, truncation of the time series to task-related data, and validation of signal-to-noise ratios across channels and participants.

Calculating Neural Synchrony with Intersubject Correlation (ISC)

Neural synchrony between speakers and listeners was calculated in the same way as in Chapter 2, as the pairwise temporal intersubject correlation (ISC) between all possible pairs of participants sharing the same preference for the video content, while watching each video. For each task, correlations between brain activity, as measured by fNIRS, were calculated across all possible pairs of participants, both those that share the same preference (congruent dyads) and those that did not (mixed dyads). This pairwise ISC was calculated using the hyperscan module in the AnalyzIR toolbox (Santosa et al., 2018). This module uses autoregressive prewhitening and robust regression to find the correlation between two NIRS time courses. Based on guidelines in the literature, a model order of P=10 was chosen for prewhitening (Santosa et al., 2017). Autoregressive prewhitening reduces the serially correlated nature of NIRS data and minimizes confounding signals produced by systemic physiology and motion artifacts, by producing an "innovations" model of the time course data containing only independent information at each time point (Barker et al., 2013). Performing pairwise robust regressions down-weights outliers remaining from motion artifacts (Santosa et al., 2017). These methods improve control of Type I errors and replace the identification, removal and interpolation of motion artifacts. Using the hyperscan module, Pearson correlations were calculated for each symmetrical pair of ROIs (e.g. speaker MPFC – listener MPFC) in each dyad across the whole timeseries.

Calculating Composite Liking

The behavioral outcome for each video in the Theater-Sports Task was a composite liking score. This score represents the mean of a four-item post-viewing questionnaire, with all items on a 5-point Likert scale: *I would buy a ticket*; *I would attend if I was given a ticket*; *I would recommend to others*; as well as overall liking (*How interested would you be in seeing the first 10 minutes of this event?).* Overall, the internal consistency for the questionnaire is high (Cronbach's $\alpha = 0.952$), suggesting that all four questions represent the concept of preference for content. Separately, liking scores for congruent (Cronbach's $\alpha = 0.878$) and incongruent (Cronbach's $\alpha = 0.923$) video content show consistency in both categories. For comparison to pairwise ISC in neural analyses, we take the absolute value of the difference between composite liking scores for each dyad, yielding difference scores between zero (i.e., no difference; both participants rated the content the same) and four (i.e., one participant rated the content at 1, while the other rated the content at 5).

Analysis Plan

Separate analyses were run for the behavioral and neural hypotheses. Hypotheses H1a and H1b predict that participants' self-reported preferences for content – identifying them as either sports or theater fans – will predict the behavioral measure of composite liking for the promotional videos of the Theater-Sports Task. These analyses were run at the person level, rather than the dyad level, yielding smaller degrees of freedom but more easily interpretable results. We updated the statistical tests run for each hypothesis from what was in the original analysis plan to reflect the complexity of the available data. For H1a, we ran a paired t-test to compare liking scores for all congruent cases – where fan preference and video type matched – to all incongruent cases, across both fan groups. We also ran two independent samples t-tests between fan groups, one for each video type, to show that fans rate their preferred video content more highly than non-fans rate the same videos. For H1b, we ran a two-way ANOVA with video congruence and fan category as predictors of liking (aov(composite_like ~ congruent*pID_cat)), replacing the preregistered paired t-tests to capture liking for preferred and non-preferred video content within fan groups.

For the neural hypotheses, where we proposed that congruence between fan preferences and video content would predict ISC, the ISC data exist only at the dyad level. To account for individual contributions to the model and the fact that all participants were part of multiple dyads, we ran multilevel regressions with the dyad members – participant one and participant two – as random effects (e.g., ISC ~ ß0 + ß1*video_congruent + (1|s1_id) + (1|s2_id), where (1|sx_id) represents a random intercept for each participant in the dyad). This approach allows us to account for the complexity of dyadic data. We have included the original, preregistered hypotheses with analysis plans below, for the record, but data for all hypotheses were analyzed as described above and in the results.

Behavioral analyses

H1a: To confirm that fans have stronger affinity for their events than do non-fans, we conduct dependent samples (paired) t-tests on a composite measure of liking, comprised of the mean over participants' (a) willingness to buy a ticket, (b) attend if given a ticket, (c) recommend the event to others and (d) desire to watch the first 10 minutes of the event, comparing (1) all congruent conditions (sports-sports & theater-theater) vs. all incongruent conditions (theater-sports & sports-theater). As a robustness check, we verify, with independent samples t-tests, between preference groups (2) that sports fans rate sports events more highly than theatre fans rate sports events and (3) that theatre fans rate theatre events more highly than sports fans rate theatre events.

H1b: To confirm that fans prefer their own category of event to the other category, we conduct a two-way ANOVA on the composite liking measure, comprised of the mean over (a) willingness to buy a ticket, (b) attend if given a ticket and (c) recommend the event to others and (d) desire to watch the first 10 minutes of the event, comparing with each fan category (i.e., sport fans' ratings of sports vs. theatre events; theatre fans' ratings of theatre vs. sports events). We also verify that the same relationships hold separately for sports fans (sports-sports vs. sports-theatre), and theatre fans (theatre-theatre vs. theatre-sports).

Neural analyses

H2a: To test whether a group of fans sharing an interest show greater ISC for interest-congruent events than the group of fans who do not share that interest, we will construct multilevel models with two random, fully crossed effects representing each person in a dyad, including two brain systems as predictors: (1) self-relevance processing (MPFC) and (2) mentalizing regions of the brain (combined DMPFC and bilateral TPJ) . These regressions take the general form: $ISC_{ROI} \sim ß0 + ß1*(predictor) + (1|s1\_id) + (1|s2\_id)$, where sx_id represents one person in the dyad. Multilevel models will be run for: (1) all congruent conditions (sports-sports & theater-theater) versus all incongruent conditions (sports-theater & theater-sports), and as a robustness check between the two fan groups for the same stimuli, i.e. (2) sports fan congruent (sports-sports) vs. theater fan incongruent (theater-sports), and (3) theater fan congruent (theater-theater) vs. sports fan incongruent (sports-theater). If different results are observed for theater and sports, follow up analyses will control for known differences in the stimuli (see Appendix C).

H2b: To test whether fans who share an interest show greater ISC in response to events congruent with their interest than events incongruent with their interest, we will construct multilevel models with two random, fully crossed effects representing each person in a dyad, including two brain systems as predictors predicting mean ISC in the same self-relevance and mentalizing ROIs between event categories, aggregated across each category as above. The multilevel models take the same general form as above: $ISC_{ROI} \sim ß0 + ß1*(predictor) + (1|s1\_id) + (1|s2\_id)$. Here, the individuals in the groups are held constant, while the categories vary. T-tests will be conducted for (1) sports fan congruent (sports-sports) vs. sports fan incongruent (sports-theater), and (2) theater fan congruent (theater-theater) vs. theater fan incongruent (theater-sports). If different results are observed for theater and sports, follow up analyses will also control for known differences in the stimuli (see Appendix C).

Results

Behavioral Results

First, we tested the behavioral preferences for each video category across both theater and sports fans. All analyses use the composite liking score, which is the mean of the scores, on a 5-point Likert scale, for the following four questions: (1) *I would buy a ticket*; (2) *I would attend if I was given a ticket*; (3) *I would recommend to others*; as well as overall liking ((4) *How interested would you be in* <u>*seeing the first 10 minutes*</u> *of this event?).*

In Hypothesis 1a, we confirmed participants' preference for content that matches their interest, within both the theater and sports fan groups. Combining all participants, we first analyzed preference scores for congruent videos – all cases where the participants' preferences matched the video content (i.e., sports fans watching sports videos and theater fans watching theater videos) – versus all cases where the participants' preferences do not match the video content. Preference for congruent content is greater across all participants than preference for incongruent content ($t(19) = 10.67$, $p < 0.001$). This suggests the promotional videos, which we designed and pre-tested to appeal to theater and sports fans, do evoke the interest of people who prefer those events but do not interest people who do not prefer those events.

To confirm that this effect occurs separately within each fan group, we ran the same paired t-test within each group. Theater fans prefer theater content over sports content ($t(10) = 6.85$, $p < 0.001$) and sports fans prefer sports content over theater content ($t(8) = 9.64$, $p < 0.001$). Composite liking scores for theater and sports content did not differ when compared without respect to participants' preferences, i.e., sports fans did not like sports more than theatre fans liked theatre ($t(19) = -0.27$, $p = 0.79$). Support for this hypothesis suggests that participants are effectively dichotomized into groups with strongly held preferences.

In Hypothesis 1b, we analyzed preferences between fan groups. Testing the effect of video congruence and the individual's fan preference on their liking for each video in a two-way ANOVA, there is a main effect of video congruence ($F(1,116) = 130.66$, $p < 0.001$) but no main effect of fan preference ($F(1,116) = 0.193$, $p = 0.66$); people liked the content that matched their preferred form of entertainment and this degree of liking did not differ between theatre and sports fans. Additionally, there is a marginally significant interaction between video congruence and fan preference ($F(1,116) = 3.66$, $p=0.058$), indicating a potentially stronger preference in sports fans for sports events (over theater events; difference in means = 2) than the preference in theater fans for theater events (over sports events; difference in means = 1.43).

Together, these results suggest that the *Theater-Sports Viewing Task* sufficiently represents interest-congruent and incongruent content in the six promotional videos, and that content preferences are accurately self-reported by the participants and are persistent over time (from screening to lab session).

Neural Results

Next, we examined participants' neural activity while viewing the promotional videos in the *Theater-Sports Viewing Task*. Using the oxygenated (HbO) and deoxygenated hemoglobin (HbR) concentrations obtained through fNIRS, we calculated mean intersubject correlation (ISC) between all pairs of participants (dyads). As the more robust measure (Cui et al., 2010), results for HbO are reported in the main paper; please see Appendix C for HbR results.

Before addressing our hypotheses (2a and 2b) about the interaction of entertainment content and individual preference within fan groups, following prior literature showing that people with shared identities (Dieffenbach et al., 2021; Leong et al., 2020) and who are friends (Baek et al., 2022; Parkinson et al., 2018) show more similar brain responses than average, we first look at whether dyads who share a preference show greater ISC than mixed dyads – those composed of one sports fan and one theater fan – regardless of the type of video they view. This analysis includes 190 dyads; 91 who have the same (congruent) preference and 99 with opposite (mixed) preferences. Since each participant was a member of multiple dyads, we ran all analyses as linear multilevel models, using two random effects to control for non-independence of participants within a dyad. Dyad congruence does not predict ISC in any region (see Table 4.1). The absence of ISC predictive of dyad congruence does not necessarily mean there is no effect of content congruence within congruent dyads.

In order to better understand whether we see task-based neural synchrony at all, we also looked at the overall distribution of ISC in the main regions of interest. Across all videos and participants, the ISC values are near zero, suggesting very low mean synchrony. Although we do not see significant mean values of ISC, at the dyad level we do see variance in the amount of correlation between individuals, with minimum and maximum ISC values between -0.21 and 0.17 (see Table 4.2).

Table 4.1

Main effect of dyad congruence on ISC across all participants

ROI (HbO)	**β**	**SE**	**CI**	**p (uncorrected)**
MPFC	3.3e-03	3.2e-03	(-0.003, 0.009)	0.30
DMPFC	2.6e-03	3.3e-03	(-0.003, 0.009)	0.43
rTPJ	4.9e-03	3.1e-03	(-0.001, 0.011)	0.11
lTPJ	5.4e-04	3.1e-03	(-0.006, 0.006)	0.86

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_congruent + (1|s1_id) + (1|s2_id))

Table 4.2

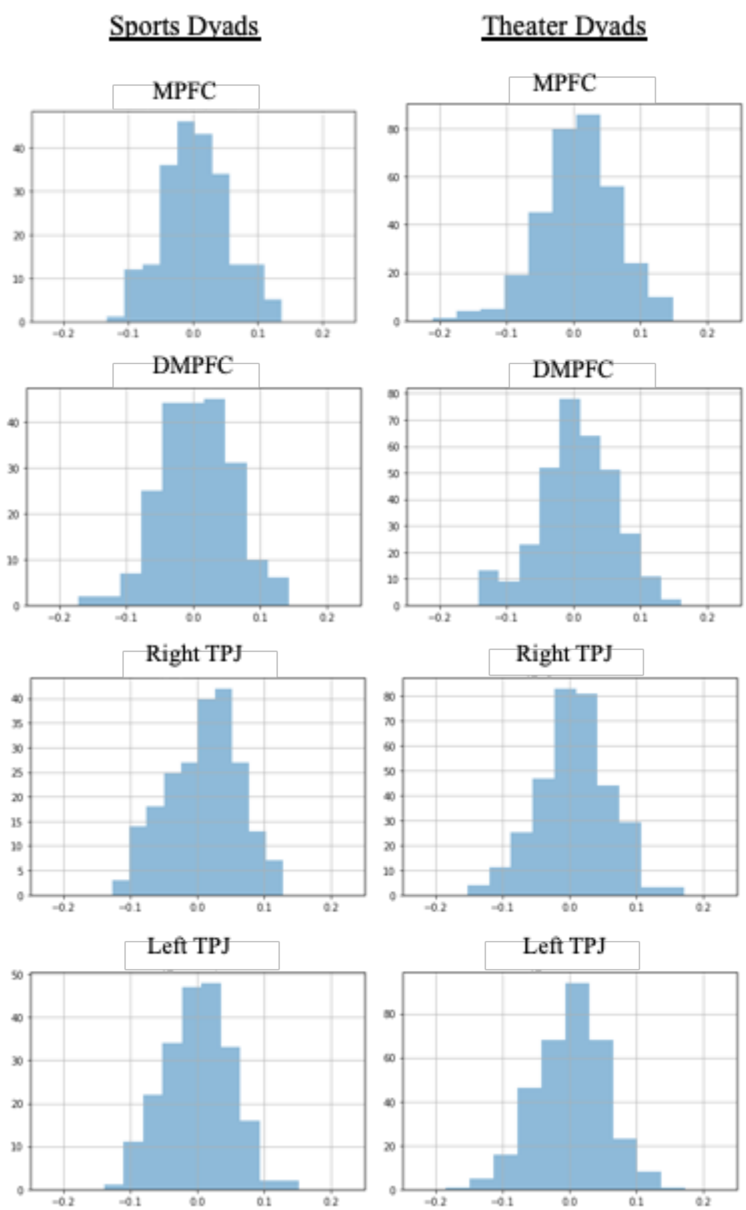
Descriptive statistics for ISC in four regions of interest, across all participants

ROI (HbO)	*(Min, Max)*	*Median*	*Mean*
MPFC	(-0.21, 0.15)	0.0057	0.0068
DMPFC	(-0.17, 0.16)	0.0064	0.0047
rTPJ	(-0.15, 0.17)	0.010	0.0074
lTPJ	(-0.19, 0.17)	0.0025	0.00095

Breaking the ISC data out by preference, we look separately ISC in each region for sports and theater fans. The distribution of ISC values is similar across both fan groups within each ROI (Figure 4.1). Since some distribution of ISC exists across dyads, we looked for a significant relationship between the behavioral liking for videos and neural synchrony.

Figure 4.1

Distribution of ISC values by dyad type and ROI



As outlined in the behavioral results, the composite liking score for a dyad is conceptualized as the difference in liking (on a 5-point scale) between the individuals in the dyad; the minimum difference is 0 (same score for the video), while the maximum difference is 4.0 (i.e., one participant rated the video as a 1.0, while the other rated the video as a 5.0). We found no significant relationship between a dyad's difference in their liking for video content and ISC in any region (Table 4.3; Figure 4.2)

Table 4.3

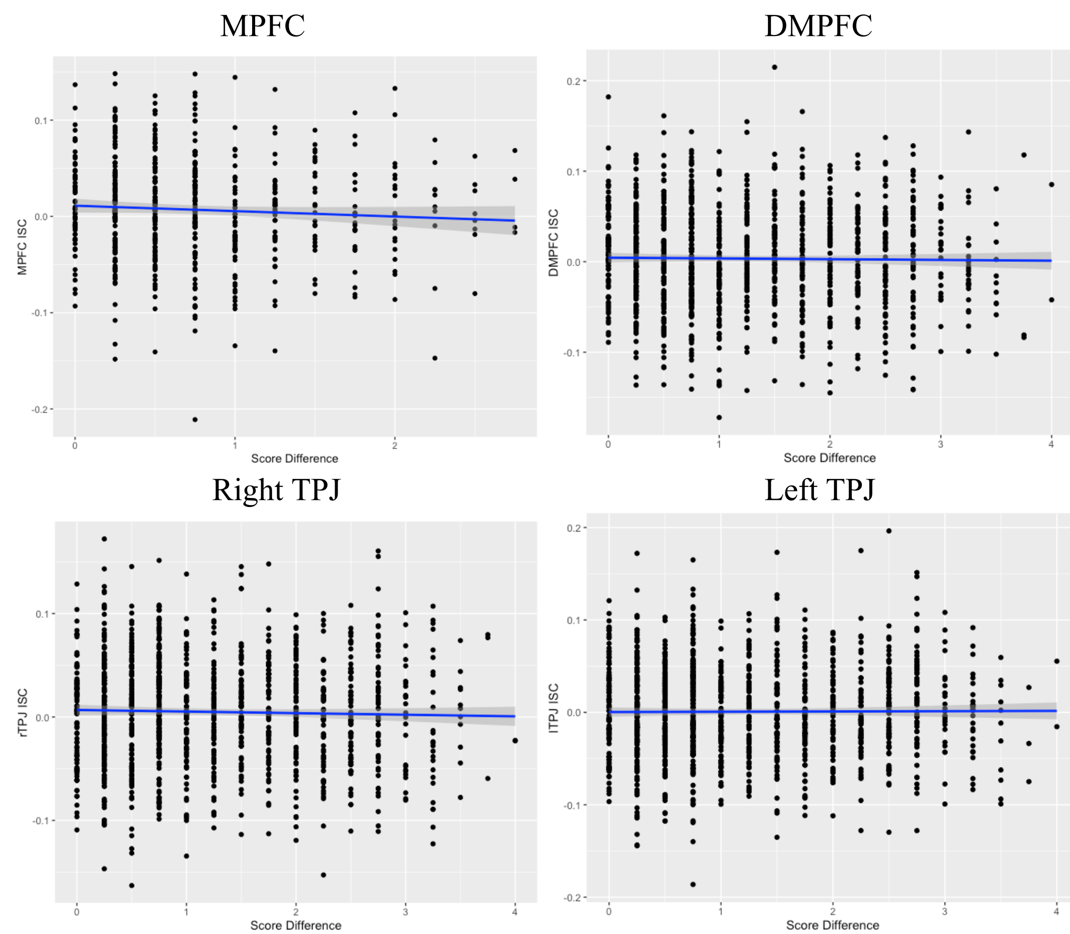
Main effect of difference in composite liking scores on ISC across all participants

ROI (HbO)	β	SE	CI	p (uncorrected)
MPFC	0.0111	0.00367	(-0.013, 0.0016)	0.13
DMPFC	-0.00196	0.00377	(-0.0096, 0.005)	0.60
rTPJ	4.26e-03	3.64e-03	(-0.0031, 0.011)	0.24
lTPJ	-0.00118	0.00349	(-0.0080, 0.0056)	0.74

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*score_diff + (1|s1_id) + (1|s2_id))

Figure 4.2

Plots of the difference in liking scores vs. ISC for all participants by ROI



Note. Multilevel regressions (ISC_{ROI} ~ ß0 + ß1*score_diff + (1|s1_id) + (1|s2_id)) show no significant relationship between mean liking for the videos and ISC in any region of interest (see Table 4.3).

Returning to our main neural hypotheses, we examine the effects of video content congruence on ISC across all participants (hypothesis 2a). Given the sizes of each participant group (N=11 theater, 9 sports), this dyadic analysis includes 55 theater fan dyads and 36 sports fan dyads. Since each participant was a member of multiple dyads, we ran all analyses as linear multilevel models, using two random effects to control for non-independence of participants within a dyad.

Analyses of two demographic factors – age and socioeconomic status (SES) – shows no difference in SES between sports and theater fans (t(16.7) = 0.83) but a significant difference in age, where sports fans (M=20.78, SD=1.30) are significantly younger than theater fans (M=23.27, SD=2.97; t(14.3) = 0.025). We included age as a covariate in the analysis of the main effect of congruence between video content and dyadic preference over all participants, and found no effect of age in predicting ISC.

In hypothesis 2a, we hypothesized that a group of fans with a shared preference for the video content show greater ISC for congruent events than the group of fans who do not share that preference (i.e., theatre fans would show greater neural ISC when watching theatre videos than sports fans watching theatre videos, and sports fans would show greater neural ISC when watching sports videos). We found no main effect of congruence on ISC between the dyad's preferences and the type of video they watched in any hypothesized ROI (see Table 4.3).

Table 4.4

H2a: Main effect of video congruence across all participants

ROI (HbO)	β	SE	CI	p (uncorrected)
MPFC	5.8e-03	4.6e-03	(-0.003, 0.015)	0.21
DMPFC	1.2e-03	4.7e-03	(-0.008, 0.01)	0.79
rTPJ	-0.0013	0.0046	(-0.01, 0.008)	0.77
lTPJ	-2.8e-04	4.4e-03	(-0.0089, 0.0083)	0.95

Note. ($ISC_{ROI} \sim ß0 + ß1*video\_congruent + (1|s1\_id) + (1|s2\_id)$)

Though we did not observe a main effect of video congruence across all videos and all participants, we ran additional models to investigate if (1) an effect of congruence exists between fan groups for each set of videos separately and (2) an effect exists within either the theater or sports fan group.

We also investigated whether congruence mattered for one set of video stimuli and not the other, looking for a difference in ISC between fan groups during sports videos and theater videos separately. There is no main effect of congruence within any ROI for either sports (see Table 4.4) or theater (see Table 4.5) videos.

Table 4.5

H2a: Main effect of video congruence for sports video stimuli

ROI (HbO)	**β**	**SE**	**CI**	**p (uncorrected)**
MPFC	-9.8e-04	6.3e-03	(-0.013, 0.011)	0.88
DMPFC	-0.00041	0.0079	(-0.016, 0.016)	0.96
rTPJ	-5.4e-04	6.8e-03	(-0.014, 0.013)	0.94
lTPJ	6.1e-04	7.4e-03	(-0.014, 0.015)	0.94

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_group + (1|s1_id) + (1|s2_id)), within data for all sports videos, where dyad group represents pairs of either sports or theater fans.

Table 4.6

H2a: Main effect of video congruence for theater video stimuli

ROI (HbO)	**β**	**SE**	**CI**	**p (uncorrected)**
MPFC	0.0073	0.0086	(-0.0092, 0.024)	0.41
DMPFC	0.0025	0.0092	(-0.015, 0.02)	0.80
rTPJ	-0.0037	0.0088	(-0.021, 0.014)	0.69
lTPJ	-0.0017	0.0075	(-0.017, 0.013)	0.83

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_group + (1|s1_id) + (1|s2_id)), within data for all theater videos, where dyad group represents pairs of either sports or theater fans.

To understand if congruence with the video content mattered in one fan group but not the other, as outlined in hypothesis H2b, analyses were run separately in all ROIs for sports dyads and theater dyads. There is no evidence of a main effect of congruence for sports dyads (see Table 4.7). For theater dyads, there is a main effect of congruence on ISC in the MPFC; however, this effect does not survive Benjamini-Hochberg correction for multiple comparisons (see Table 4.8).

Table 4.7

H2b: Main effect of video congruence for sports fans

ROI (HbO)	**β**	**SE**	**CI**	**p (uncorrected)**
MPFC	4.9e-03	6.9e-03	(-0.0086, 0.018)	0.48
DMPFC	2.8e-03	7.2e-03	(-0.012, 0.017)	0.70
rTPJ	3.9e-03	7.2e-03	(-0.010, 0.018)	0.58
lTPJ	1.5e-03	6.6e-03	(-0.011, 0.014)	0.86

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*video_cat + (1|s1_id) + (1|s2_id)), within data for sports fans, where video category represents sports or theater promotional videos.

Table 4.8

H2b: Main effect of video congruence for theater fans

ROI (HbO)	**β**	**SE**	**CI**	**p (uncorrected, corrected)**
MPFC	1.3e-02	6.1e-03	(0.00081, 0.025)	0.037*, 0.15
DMPFC	3.9e-03	6.1e-03	(-0.0082, 0.016)	0.53, 0.94
rTPJ	4.2e-04	5.9e-03	(-0.011, 0.012)	0.94, 0.94
lTPJ	4.6e-04	5.8e-03	(-0.011, 0.012)	0.93, 0.94

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*video_cat + (1|s1_id) + (1|s2_id)), within data for theater fans, where video category represents sports or theater promotional videos.

Results for HbR are included in Appendix C. For sports dyads, there is an effect of video congruence in the DMPFC, but it does not survive multiple comparisons correction ($t(204.5) = 2.17$, $p = 0.03$, $p_{corr} = 0.12$), and hence is not considered robust.

Discussion

In this study, we tested the idea that people with similar identities and preferences would share similar neural responses to relevant media content. We successfully recruited theater and sports fans, and people's preferences for content did align with their identity – theater fans prefer theatre events, and sports fans prefer sports events. Both groups of fans preferred their own type of content to similar degrees.

Contrary to our expectations, we did not observe congruent brain responses that were more similar for fans of either type of content than non-fans. Also contrary to our expectations, the overall intersubject correlation between audience members was not greater for fans who shared preferences than those who did not, and the overall mean ISC was not distinguishable from zero. This is surprising given the substantial body of literature showing that media stimuli typically drive strong ISC in audiences, and that this is particularly true for friends and people with shared identities. Listening to the same story or watching the same movie reliably provokes synchronous brain activity in regions associated with both auditory and visual processing, as well as regions involved in higher-order cognition (Hasson et al., 2004; Stephens et al., 2010). Particularly relevant to this investigation, studies have found that media produce ISC in mentalizing regions (Chen et al., 2017; Schmälzle et al., 2015; Stephens et al., 2010). For audiences who watch the same movie, both viewing the movie and verbal recall of movie scenes generate ISC. Within-subject ISC suggests that viewing and recall engage similar brain regions; between subjects, ISC supports the idea that shared experiences promote similar memories and neural processes across individuals, even when recounted with different language (Chen et al., 2017). It is possible that both the task design and the nature of entertainment preferences limit our ability to see neural synchrony in mentalizing and/or self-relevance regions in this study, or that we are not well powered to detect these effects. As such, the remaining results should be interpreted with this in mind.

Inherent differences in stimulus content also influence group ISC. Rhetorically powerful political speeches produce greater ISC in an audience of listeners than speeches judged to be rhetorically weak (Schmälzle et al., 2015). Extending this finding across domains, health messages perceived as more effective produce greater ISC than weaker health messages (Imhof et al., 2020). The fact that we do not find significant ISC within audiences who share fan identities could be due to differences in the video stimuli or the technical limitations of neuroimaging with fNIRS. Unlike the previous studies in this dissertation, which both used a long-form (>4 minutes) autobiographical story video (similar to Y. Liu et al., 2017; Stephens et al., 2010), this study used multiple short (~90 sec) promotional videos. Shorter, non-story videos can promote ISC, as we see in Schmalzle et al. (2015) and Imhof et al.(2020), but the videos included in these studies varied in message strength and were intentionally chosen to be persuasive. In our study, the videos were constructed by the research team around a common script to control for any variability in emotional language or enthusiasm; see Appendix C for scripts for all six videos. As such, it is possible that our videos were generally less engaging than either the autobiographical stories or the intentionally persuasive political and health messages. Since we did not analyze ISC in areas associated with auditory or visual processing, it is also possible that our videos produce ISC at a basic processing level, but not in mentalizing or self-relevance regions.

Our finding that brain responses in groups of fans was not more similar to one another than to non-fans was surprising. In addition, an exploratory analysis did not show a relationship between the closeness of their preference ratings and their brain responses to the video content. Past research examining intersubject correlation in audiences shows stronger ISC as a function of different forms of identity. In a study of within- and between-group ISC in politically conservative and liberal individuals, both groups experienced greater within-group ISC in the DMPFC during exposure to political messages representing both viewpoints. The similarity between an individual's brain activity and the group average ISC of the conservative or liberal group predicted attitude change in line with the group whose brain activity mirrors their own (Leong et al., 2020). Individual differences in tolerance of uncertainty predict ISC in both conservative and liberal groups, with less tolerant individuals in both groups showing more similar neural activity to their peers (van Baar et al., 2021).

Group ISC can also predict social closeness. Parkinson and colleagues (2018) found that ISC in certain brain regions during movie clip viewing predicted social distance in a network of students. This neural similarity predicted social distance above and beyond demographic measures, such as age, gender, ethnicity, nationality and handedness. Similarities in connectivity within the brain in the absence of stimuli may also predict social relationships. Intra-individual functional connectivity at rest, particularly in (the DMN) areas associated with attention, predicted social distance in a rural Korean village community (Hyon et al., 2020). Neural similarity may also reflect an individual's position in their social network. More popular individuals show brain activity that is more similar to their network's mean ISC than less popular individuals (Baek et al., 2022). Based on these results, we would have expected that people with more similar identities would have shown more similar neural responses.

While membership in a group, whether by shared attitudes or friendship ties, can predispose individuals to have similar neural activity, not all group identities are equal. First, although the people in this study strongly identify as being sports or theater fans, there may still be individual differences in the degree to which they see others who share their preference as members of the same in-group. Group identity may be more salient for activities more specific than general sports or theater attendance. Selecting participants as sports or theater fans does not take into account that two sports fans might prefer different sports (i.e., basketball fan vs. football fan, or even identify with specific teams, rather than the sport as a whole) or a theater fan might exclusively attend musicals and not identify with other types of theater. This study included three distinct cases of each event types (e.g., football, soccer and basketball events as sports videos) in an attempt to reduce case-category confound. In-group behavior, however, is more commonly seen not around sports at large or between different sports (i.e. basketball fans vs. football fans), but around specific teams within a sport (Fink et al., 2002; Wann & Branscombe, 1993). Although the participants as a whole liked content from their preferred category, neural synchrony for an audience group may be tied to a more specific affinity for a certain sport, team, genre of performance or even a specific play. Synchrony among fans of the musical *Hamilton*, for example, may be more robust than synchrony among an audience who prefer any theatrical performance.

Second, contrasting sports and theater, although often dichotomized in research on leisure participation, may not be an accurate representation of how people think about their preferences in everyday life. A large scale survey of participation in sports and theater find them to be correlated and complementary rather than exclusive (Hallmann et al., 2017). Though there is some evidence that fNIRS neuroimaging can distinguish subjective preference (J.-Y. Kim et al., 2016) as well as the strongly held beliefs of political partisans (Dieffenbach et al., 2021), the definition of the out-group may not be so constant and identifiable as it is for individuals holding opposing political views. Strength of the identity is likely weaker when it is based on non-exclusive preferences.

Despite this and other possible flaws in the study concept, there are a number of strengths in this design. Including two preference categories (i.e., sports and theater) helps to control for confounds about the relatedness of synchrony to a given interest. The design of the stimuli videos provides a balance of external validity and a high degree of experimental control. Finally, this is one of a relatively limited number of studies using fNIRS to investigate neural signatures of group membership.

fNIRS itself has benefits and flaws as a neuroimaging technology. It is a wearable, lower-cost alternative to fMRI which allows for the imaging of different populations in novel environments; however, fNIRS signal quality is highly dependent on contact between cap optodes and the scalp, so any physical barriers (e.g., hair) or photon-absorbing material (e.g., melanin) can decrease signal quality (Ferrari & Quaresima, 2012; Webb et al., 2022). fNIRS is also susceptible to differences in cap placement between participants and, without a method of normalizing channel locations in space across participants, it is difficult to make spatially-specific claims at the channel level.

The sample size of our study (n=20, 11 theater fans, 9 sports fans), although in line with other studies of neural synchrony (Y. Liu et al., 2017; Schmälzle et al., 2015), is also a limitation. Although a post-hoc power analysis suggests we were powered to detect an effect size of d = 0.41 at 80% power, a lack of related literature makes it difficult to know what effect size we could reasonably expect for our task. Recruiting individuals with both strongly held preferences for sports or theater events and hair types that would maximize the fNIRS signal proved to be difficult and, ultimately, necessitated relaxing the preference criteria for the last participant recruited. Future studies of neural synchrony in audiences based on preference using fNIRS should seek to retain audience groups with strongly held preferences, possibly by choosing different preference categories, balanced with the technical limitations of fNIRS.

CHAPTER 5

Conclusion

Overview

In this dissertation, we examine the role of neural synchrony – between communicators and across audiences – in the successful communication of autobiographical stories and entertainment messages. Across three studies, we trace the progress of a story, from the original storyteller to an audience (Chapter 2) and transmission from an audience to a set of subsequent listeners (Chapter 3), as well as looking at the relationship between synchrony and audience preferences for entertainment content (Chapter 4). We conceptualize successful communication in different ways depending on the psychological task of the listeners. In storytelling, understanding the storyteller's emotional states constitutes the successful communication of emotional story content. In retelling a story to an audience, the combination of seeming authentic and appealing, and getting listeners to have a positive experience of the story – in short, retelling the story as believably as the original storyteller – indicates successful story transmission. Finally, entertainment messages are successful when they appeal preferentially to an audience who share a preference for that content.

Our results show mixed support for a link between neural synchrony and successful communication. Between a speaker and her listeners, intersubject correlation (ISC) in regions of the brain involved in mentalizing predicts the listener's accuracy at understanding the speaker's emotional states and how they change over the course of her story. This empathic accuracy has important consequences for feelings of connection and satisfaction between communicators (Reis et al., 2017; Sened et al., 2017). Among an audience of listeners who go on to retell a story, neural synchrony in a region involved in processing the self-relevance of information predicts how their story retelling will be received by a subsequent audience of listeners. Subsequent listeners find story retellers more authentic and appealing, and have a better experience listening to the story, if the retellers self-relevance processing mirrors the mean processing for the whole audience of retellers when they first heard the story. Having a normative understanding of a story indicates that audience members share a world-view or interpretation of story events (Yeshurun et al., 2017). Having a common world-view may increase the accessibility of a story when those listeners go on the share that story with others (Baek et al., 2022; Parkinson et al., 2018).

Finally, we proposed that audience preference matters for both successful communication and neural synchrony. In response to entertainment messages promoting either sports or theater events, audiences of sports and theater fans' liking for the events aligns with their overall entertainment preferences. There is, however, very little neural synchrony within audiences who share preferences and no relationship between neural synchrony and the congruence of audience preference with message content. Prior studies of neural synchrony in groups of political partisans suggests that individuals experience greater neural synchrony with others who share their political attitudes (Leong et al., 2020), and that neural synchrony can effectively discriminate between individuals based on their political affiliation (Dieffenbach et al., 2021). Our results suggest that neural synchrony between individuals who share preferences for entertainment is negligible. Attitudes or preferences for entertainment, such as sports and theater events, may not be encoded in the brain in the same way as political attitudes. It is also possible that the identities associated with being a sports or theater fan are not effectively dichotomized. Individuals who share the broad identity as a sports fan may not see themselves as part of an in-group with other self-identified sports fans; likewise, they may not see theater fans as a salient out-group (Bettencourt et al., 2001). The classification of individuals as sports or theater fans is broad. Neural synchrony may be more likely among people who share more specific preferences, either by genre of the event (e.g., musicals or basketball) or for specific events (e.g., the musical *Hamilton* or the basketball team the Golden State Warriors). Fan behaviors, such as producing derivative art based on a play or engaging in celebration with others who support the same team, may be tied to specific individuals (e.g., star performers) or social features, such as a team's home city (Fink et al., 2002). Further research is needed to map the extent to which neural synchrony among audiences can predict elements of social and personal identity.

Strengths and Limitations

The studies in this dissertation share a number of strengths and, especially methodological, limitations. With tasks based on real-life autobiographical stories and promotional materials for real entertainment events, these studies balance ecological validity with experimental control. Neuroimaging with fNIRS during naturalistic communication also balances the intrusiveness of neuroimaging with the ability to communicate in a comfortable environment (Yücel et al., 2017). fNIRS is a portable, wearable, lower-cost neuroimaging technology appropriate for some communication questions (Ferrari & Quaresima, 2012). fNIRS is relatively tolerant for head motion, which makes it possible to use when participants are speaking (Hirsch et al., 2018; X. Zhang et al., 2017). For future research in interpersonal or group communication, fNIRS offers the opportunity not only to scan neural activity sequentially in communicators, but also to scan two or more communicators simultaneously (Hamilton, 2020).

As with any technology, fNIRS also has a number of limitations. Although fNIRS makes neuroimaging possible for individuals who are not able to participate in fMRI studies, it is not easily implemented across ethnically diverse adult populations. Phenotypic differences in hair color and texture, and skin color, change how easily fNIRS systems can generate useable data; any material that prevents contact between the scalp and the fNIRS sources and detectors increases the difficulty of participant setup and signal processing for analysis (Webb et al., 2022). Although several fNIRS studies have been conducted with participants of African and Asian descent (Lloyd-Fox et al., 2019; Perdue et al., 2019), they are often designed for infants, who have thinner skulls and less hair, increasing the ability of near-infrared light to pass through brain tissue (Aslin et al., 2015). In adult populations, studies may be designed to focus on prefrontal cortical regions, where there is no hair to interfere with optode-scalp contact (Dieffenbach et al., 2021). We are actively in conversation with the engineers who design fNIRS systems and analysis software, as well as fellow social and neuroscientists who study adult populations to advance the ability of fNIRS to be used for participants of all ethnic backgrounds (Webb et al., 2022; Yücel et al., 2021). In this dissertation, however, the lack of racial and ethnic diversity in our sample is a significant limitation in interpreting our findings. Specifically, limiting recruitment reduces the generalizability of our findings to other racial and ethnic groups. In addition, variability in signal quality according to hair color and type can add noise that is confounded with racialized life experiences. As such, although our recruitment criteria alleviated some possible measurement limitations with fNIRS (since having participants with lighter hair colors eliminated hair color as a source of variation in signal quality), our findings are in turn restricted to a much narrower range of identities that biases our findings.

In addition to the limitations on recruitment and measurement imposed by fNIRS, our choice to focus on women participants creates another potential source of bias. In Study 1 and Study 2, where we were measuring synchrony during story listening, our original storytellers were both women. Previous research on communication in gender-matched versus mixed gender dyads suggests that woman-woman dyads show greater self-disclosure (McKinney & Donaghy, 1993), which is related to greater empathy between communicators (Rochat, 2022). In Study 1, the storyteller was known to the research team and recruited based on previous knowledge of her story. In Study 2, the story chosen originated from a pilot study on story elicitation, in which stories were gathered from both men and women. We chose the original story for Study 2 based upon the story length, flow of narrative events and vocal fluency (Norrick, 2007). Unfortunately, the longest and most cohesive story generated by a man lacked narrative flow and vocal fluency, so we chose to proceed only with the woman's seed story. The lack of man storytellers and man participants across all studies potentially limits the behavioral variance we see, particularly when measuring empathic accuracy. Future research with a broader range of race, ethnicity and genders is essential for this research program.

Future Directions

The studies in this dissertation show mixed support for the role of neural synchrony in successful communication and, as such, offer many avenues for future research. First, future studies should attempt to replicate the relationship between speaker-listener neural synchrony and listeners' memory for stories. Although we found an interaction effect between listener condition and speaker-listener ISC in the right temporal region (but no main effect of ISC; Chapter 2) and a marginal main effect of ISC in the MPFC among an audience of listeners (Chapter 3), we cannot offer evidence that speaker-listener ISC predicts factual accuracy (Stephens et al., 2010). This finding was not reported in a partial fNIRS replication of the same storytelling paradigm (Y. Liu et al., 2017) and, given the lack of findings in our studies, would benefit from further replication with multiple neuroimaging modalities.

Next, future studies should consider two additional analytical approaches to storytelling studies with fNIRS. Lagged analysis, where the speaker's neural data is shifted +/- 2 to 5 seconds before and after the listener's neural data, helps identify areas of the brain where the speaker's activity precedes or follows the listener's activity (Dikker et al., 2014; Hasson, Yang, et al., 2008) This accounts for the different psychological processes involved in speech production and comprehension, and could shed light on differences in mentalizing activity during storytelling (Silbert et al., 2014).

Similarly, windowed analysis of ISC, based upon a scene-by-scene breakdown of a story to identify particularly salient events would help to identify how attentional engagement affects neural synchrony (Song et al., 2021). It is possible that ISC over the duration of a story is driven by discrete events which are tied to particular cultural schemas, such as being rejected by a romantic partner (as in the story from Chapter 2) or being pulled over by the police (as in Chapter 3). Knowing how ISC fluctuates over the course of a story and how individual scenes or events alter ISC would provide insight into individual differences in narrative processing and how narrative features may provide common points of self-relevance or mentalizing for an audience.

In general, future studies of neural synchrony in successful communication can build upon the studies in this dissertation by exploring the boundaries of both stories and group identities. In studies of storytelling, neural synchrony seems to underlie a sense of normativity – a shared understanding of the speaker's emotions and story events. In the same way that humor research has incorporated violations of expectation into jokes to explore comprehension (Coulson & Williams, 2005), finding or creating narratives which violate expected schemas could further our understanding of neural synchrony and narrative processing. Expanding on the possibilities of windowed analysis suggesting whether specific story events drive ISC, contrasting speaker-listener and audience ISC in stories with unexpected versus expected events would provide evidence for the relationship between shared understanding and synchrony. In story retelling, where we found evidence for neural synchrony among an audience of listeners as a marker of normative story understanding, it would be beneficial to combine this paradigm with network-based approaches to neural synchrony. Existing neural homophily among friends (Parkinson et al., 2018) may moderate speaker-listener synchrony during story listening. Sharing autobiographical stories between friends is a form of self-disclosure, which fosters social connection between close others and produces greater neural synchrony in neurotypical adults (Asher et al., 2020). Likewise, since more popular individuals in a network show greater neural synchrony with the mean ISC for the group (Baek et al., 2022), they may also produce story retellings which are more successful at propagating through future audiences. Disentangling ISC as a function of a story reteller's network position from the ISC required to generate perceived authenticity, speaker appeal and overall experience in listeners would provide insight into how the social identity of the story reteller matters for story transmission.

Along with exploring how listeners' narrative comprehension and speaker's social position affect neural synchrony, future studies should examine the boundary conditions of ISC in groups. While substantial literature exists showing neural synchrony within groups who share political attitudes (Dieffenbach et al., 2021; Leong et al., 2020), and that neural synchrony can be generated by prompting participants to interpret story events in a similar fashion (Yeshurun et al., 2017), relatively little is know about other shared attitudes or beliefs which may produce neural synchrony in groups. In Chapter 4, we looked for neural synchrony within audiences of sports and theater fans, but found no evidence that those individuals who shared a preference for either type of entertainment also experienced shared neural synchrony. In addition to examining the specificity of the social identity – perhaps fans of the Golden State Warriors exhibit greater ISC than people who consider themselves sports fans – future research could look to both the emotional content of the entertainment messages and whether the role of experience informs an individual's sense of identity. The promotional videos created for our study were designed to minimize differences in emotional content; within political messages, however, ISC increased in messages with greater emotional language (Leong et al., 2020), suggesting that message design even within the context of sports and theater entertainment may influence neural synchrony within fan groups.

Finally, for fan identities, which can originate from participation in sports and theater activities, first-hand experience with sports or arts may moderate neural synchrony. When processing sports-related language, individuals with professional or collegiate experience as players show greater neural activation when processing sports-specific sentences (Beilock et al., 2008). Individuals who participated in team sports show greater synchrony during a cooperative drawing task than non-participants (Li et al., 2020), suggesting that the experience of coordinating with others during games may modulate synchrony in nonverbal communication. With sports and theater fans, individuals who share an experience of training in a given sport or art form, may show greater synchrony during messages promoting interest-relevant events than individuals who have not experienced training in that sport or art. Experience, as part of a fan identity, may moderate neural synchrony in groups of fans.

In conclusion, this dissertation provides mixed support for the role of neural synchrony in the successful communication of stories and entertainment messages. While speaker-listener synchrony in mentalizing and audience synchrony in self-relevance processing regions are each indicative of elements of successful communication, much work remains to understand how different characteristics of stories and storytellers affect neural synchrony during storytelling. While some forms of shared identity, such as political attitudes, do produce neural synchrony, preference for entertainment messages within audiences of fans does not. Exploring both the message characteristics and the boundaries of shared identity may provide insight into how emotion, identity and experience shape neural synchrony between individuals. The studies in this dissertation should be seen as stepping stones to further our understanding of how synchronous brain activity across pairs of communicators and audience groups may influence successful communication.

APPENDICES

Appendix A: Chapter 2 Supplemental Materials

Story Transcript

Last year I was working at a hedge fund that I never expected I would ever work at. I studied neuroscience in college, and I got recruited to work there because a friend suggested my name to them. So, after I graduated college, I ended up at this hedge fund that was nothing like I'd ever experienced before. Essentially, we had to rate each other on a scale of 1 to 10, on every sort of attribute or behavior, because this place had a theory that if we could tell one another our weaknesses, then we could overcome them better. For example, if I were in a meeting and I were giving a presentation, I could be rated on a scale of 1 to 10, on like a 3 for brightness and a 5 for composure and a 2 for higher level thinking, which essentially translates while I'm talking, being told that I'm dumb. And you see this feedback in real time. So essentially the whole place was structured around giving each other negative criticism, so that everyone could kind of become more resilient and more able to overcome the things that they're bad at and more productive and efficient. And, this was totally different from what I had done in the past. My work was mainly with people who were very depressed and anxious, and people who shared with me difficult life experiences, so for me to have gone from that – being around depressed people who are sharing their most intimate feelings with me – to an environment where I was expected to criticize and be criticized 100% of the time was really hard. And at the time I had actually, I was dating someone, and I had met him within 3 days of moving to New York after college for this job. And I started work. I simultaneously was dating him during the first week that I even started working there. So our relationship started from the time I started working there and he was really with me throughout the whole thing. He also worked in finance, so I would call him every time I was struggling or crying or something weird happened and I didn't understand how the world of finance worked. And so towards the end of the year last year, last summer, we decided to take our first vacation together. And we went to Italy for 14 days and it was amazing. It was my first time getting away from this sort of crazy environment I had been in, and I had so much fun. I fell in love with Italy, and when I came back to work the week after that 2-week trip, I didn't tell anyone and I decided to quit my job that Friday because I decided that it was time for me to stop working there, that life was so much more beautiful and enjoyable outside of this place where everyone was so mean to one another. So I quit my job without telling anyone and I went home that night and told my boyfriend that I quit my job, because I was really excited to tell them because that meant we would have more time to have fun, to go out. I wouldn't be calling him crying anymore. And we went out to sushi, my favorite sushi restaurant in New York City, called Momoya. And I had a lychee-tini and we celebrated till late in the night and then we go home. And then the next morning, it was a Saturday, and I woke up to him crying. He woke me up bawling. And I had thought that someone had died, that something terrible had happened 'cause I wasn't used to him crying like that. And the first thing he said to me was that he doesn't want to be in a relationship anymore, and that was really surprising cause, it was, I realized in that moment that the life that I had known in the past, like, 12 months had shifted and changed completely within less than 24 hours. And, I asked him why and he couldn't tell me why and to this day I still don't know why we broke up. I do know he sent an email to me the next week that said that he just thought we were really different. But he didn't want to talk to me after that, so I still don't know why we broke up and it was a really traumatic time in my life because my plans did not go to plan.

Length: 279 seconds

Word Count: 761

Factual Accuracy Rubric

Table A.1. Coding Sheet. The following 66 facts and phrases were rated as either present (1) or absent (0) for each of the re-told stories. Facts were considered present if the information was mentioned at all, regardless of episodic placement or order. Two raters, blind to condition, compiled factual accuracy ratings by listening to each story twice. Analysis was conducted using the overall coding sheet score.

Item	Original Text	Factual Content or ***Phrase*** (S = speaker)
1	"Last year"	The events occurred last year
2	"I was working at a hedge fund"	Speaker (S) was working at a hedge fund
3	"that I never expected I would ever work at"	S had not planned to work at the hedge fund
4	"I studied neuroscience"	S studied neuroscience
5	"in college"	S attended college
6	"and I got recruited to work there"	S was recruited to work at the hedge fund
7	"because a friend suggested my name to them"	The recruitment came through a friend
8	"So, after I graduated from college"	S started work after graduating from college
9	"that was nothing like I'd ever experienced before […] This was totally different from what I had done in the past "	The work was unlike work S had done in the past
10	"We had to rate each other"	S and coworkers rated each other…
11	"on a scale of 1 to 10"	***Mentions numbers used for rating scale***
12	"On every sort of attribute or behavior"	…on personal characteristics and behavior
13	"Because this place had a theory that if we could tell one another our weaknesses then we could overcome them better. […] So that	Point of the rating system was to become better at work (resilient, overcoming weaknesses, more productive, efficient)

	everyone could become more resilient, more able to overcome the things that they're bad at, more productive and efficient"	
14	"For example, if I were in a meeting and I were giving a presentation I could be rated 3 for brightness and a 5 for composure and a 2 for higher level thinking"	S gives an example of the rating system
15	"which translates while I'm talking, that I'm dumb"	The rating system made S feel dumb
16	"You see this feedback in real time"	Rating system was presented to workers in real time
17	"Whole place was structured around giving each other negative criticism […] an environment where I was expected to criticize and be criticized 100% of the time"	***Mentions criticism in the workplace***
18	"My work was mainly with people who were very depressed and anxious"	S described past work with depressed individuals
19	"and people who shared with me difficult life experiences […] being around depressed people who are sharing their most intimate feelings with me"	…continued description of past work
20	"Was really hard"	S found transitioning to the hedge fund hard
21	"And at the time I actually was dating someone […]"	S was dating someone
22	"I started work and simultaneously was dating him during the first week that I started. So our relationship started from the time I started working there"	S and boyfriend began dating during her first week at the hedge fund
23	"I had met him within 3 days of moving"	S met her boyfriend within 3 days of moving
24	"to New York"	***Phrase***

25	"He was really with me throughout the whole thing"	S and boyfriend were together through her time at the hedge fund
26	"He also worked in finance, "	S boyfriend worked in finance
27	"knew how the world of finance worked"	S boyfriend understood her workplace environment
28	"I would call him every time I was struggling or crying or something weird happened and I didn't understand"	S relied on boyfriend for support with workplace issues
29	"Towards the end of the year last year, last summer"	***Mentions of either time, or "last year"/"last summer"***
30	"We decided to take our first vacation together"	S and boyfriend took a vacation
31	"We went to Italy"	They went to Italy
32	"for 14 days […] 2-week trip,"	***Mentions of one or both: "14 days" or "2 weeks"***
33	"It was amazing […] I had so much fun […] I fell in love with Italy"	S loved Italy
34	"It was my first time getting away from this sort of crazy environment I had been in"	***Mentions "getting away" and/or "crazy environment"***
35	"When I came back to work"	***Mentions "back to work" or "to New York"***
36	"the week after that trip"	***Mentions of "the week after," "the next week," etc.***
37	"I decided that it was time for me to stop working there […] I decided to quit my job"	S decided to quit her job
38	"that Friday"	***Mentions "Friday"***
39	"Life was so much more beautiful and enjoyable outside of this place where everyone was so mean to one another"	S felt life was better ("beautiful" , "enjoyable") away from hedge fund
40	"I quit my job without telling anyone"	S quit without telling anyone
41	"I went home that night"	S went home (that night)
42	"told my boyfriend that I quit"	S told her boyfriend she quit
43	"I was really excited to tell him"	S was excited to tell him

44	"because that meant we would have more time to have fun, to go out."	S thought she and boyfriend would have more fun since she quit…
45	"I wouldn't be calling him crying anymore."	…because S wouldn't lean on him for support about work
46	"We went out to sushi,"	S and boyfriend went out for sushi
47	"my favorite sushi restaurant in New York City"	S and boyfriend went out to her favorite restaurant
48	"Called Momoya"	***Mentions name "Momoya" or "Moya"*** *(sound in video is unclear)*
49	"And I had a drink"	S had a drink *(if mentioned having a lychee-tini but not this phrase, still give a point for this)*
50	"lychee-tini"	***Phrase***
51	"We celebrated till late in the night and then we go home."	***Mentions either "late night" or going home***
52	"And then the next morning,"	***Phrase***
53	"it was a Saturday,"	***Mentions "Saturday"***
54	"I woke up to him crying. He woke me up bawling"	S woke up to boyfriend crying
55	"And I had thought that someone had died, that something terrible had happened"	S thought something bad had happened ("someone had died," "something terrible had happened," etc.)
56	"I wasn't used to him crying like that"	S was not used to boyfriend crying
57	"The first thing he said to me was that he doesn't want to be in a relationship anymore"	Boyfriend broke up with S
58	"And that was really surprising"	S was surprised
59	"I realized in that moment that the life that I had known in the past 12 months had shifted and changed completely within less than 24 hours."	***Mentions that her world completely changed in a very short period of time***
60	"I asked him why He couldn't tell me why. To this day I still don't know why we broke up. […] I	***Mentions that she doesn't know why they broke up***

	still don't know why we broke up"	
61	"I do know he sent an email to me"	Boyfriend sent S an email
62	"the next week"	***Mentions "next week," "a week later," etc.***
63	"Said that he just thought we were really different"	***Mentions "different"***
64	"But he didn't want to talk to me after that"	***Mentions of not talking again***
65	"It was a really traumatic time in my life"	S experienced trauma
66	"because my plans did not go to plan."	***Phrase***

fNIRS Montage

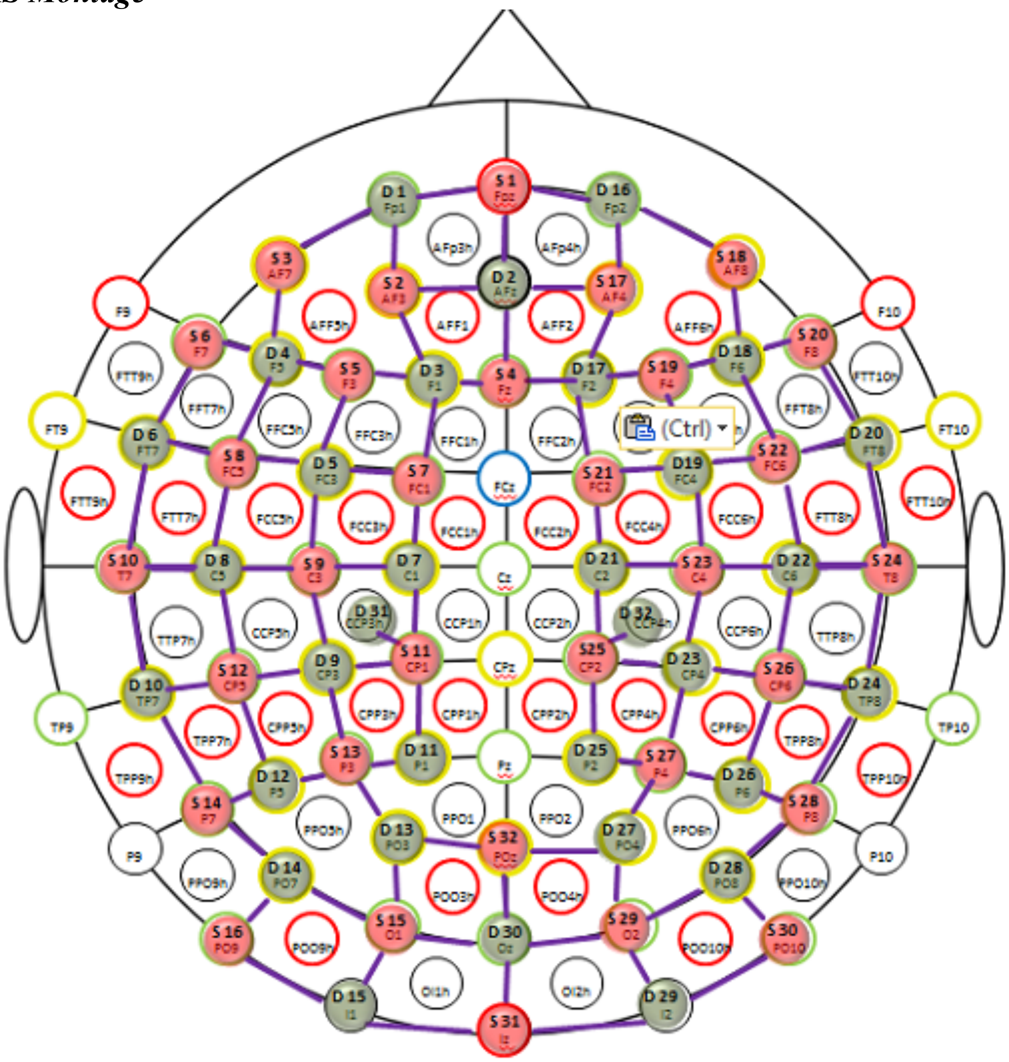


Figure A.1. fNIRS Montage on the International 10-20 system. Red icons represent source optodes, which emit near-infrared light at 760nm and 850nm (i.e., S1 = source 1). Green icons represent detector optodes, which measure photons after they pass through brain tissue (i.e., D1 = detector 1). Purple lines represent channels, where neighbor detectors are programmed to detect signal from neighboring sources. This montage contains 102 channels covering the MPFC, DMPFC, bilateral temporal regions, bilateral TPJs, visual cortex and other regions.

Additional Results

Deoxyhemoglobin (HbR) Results for Preregistered Hypotheses

Table A.2

Models predicting empathic accuracy by ROI (HbR) in the story listening task

ROI (HbR)	Main Effect Model			Interaction Model		
	β (SE)	**95% CI**	**t (p_{corr})**	**β (SE)**	**95% CI**	**t (p_{corr})**
MPFC						
ISC	-0.27 (0.26)	(-0.78, 0.24)	-1.07 (0.51)	-0.068 (0.39)	(-0.84, 0.70)	-0.18 (0.87)
Condition				0.038 (0.02)	(-0.005, 0.08)	1.77 (0.14)
Cond*ISC				-0.41 (0.51)	(-1.43, 0.61)	-0.81 (0.83)
DMPFC						
ISC	0.0058 (0.25)	(-0.48, 0.49)	0.024 (0.99)	-0.13 (0.31)	(-0.74, 0.48)	-0.42 (0.87)
Condition				0.038 (0.022)	(-0.006, 0.082)	1.71 (0.14)
Cond*ISC				0.11 (0.53)	(-0.94, 1.17)	0.22 (0.83)
rTPJ						
ISC	0.32 (0.23)	(-0.14, 0.78)	1.39 (0.40)	0.19 (0.33)	(-0.46, 0.84)	0.58 (0.87)
Condition				0.030 (0.023)	(-0.015, 0.074)	1.31 (0.19)
Cond*ISC				0.12 (0.47)	(-0.82, 1.07)	0.26 (0.83)
lTPJ						
ISC	0.029 (0.25)	(-0.47, 0.53)	0.12 (0.99)	0.058 (0.33)	(-0.60, 0.71)	0.18 (0.87)

Condition				0.037 (0.022)	(-0.007, 0.081)	1.67 (0.14)
Cond*ISC				-0.13 (0.51)	(-1.14, 0.88)	-0.26 (0.83)
rTemporal						
ISC	0.39 (0.23)	(-0.067, 0.84)	1.70 (0.33)	0.16 (0.32)	(-0.47, 0.79)	0.50 (0.87)
Condition				0.033 (0.021)	(-0.009, 0.075)	1.55 (0.15)
Cond*ISC				0.45 (0.45)	(-0.45, 1.34)	1.00 (0.83)
lTemporal						
ISC	0.61 (0.26)	(0.11, 1.12)	2.42 (0.13)	0.20 (0.34)	(-47, 0.87)	0.58 (0.87)
Condition				0.038 (0.020)	(-0.002, 0.078)	1.88 (0.14)
Cond*ISC				0.97 (0.49)	(-0.005, 1.95)	1.99 (0.36)
Visual						
ISC	-0.003 (0.24)	(-0.47, 0.47)	-0.013 (0.99)	0.049 (0.30)	(-0.54, 0.64)	0.17 (0.87)
Condition				0.041 (0.23)	(-0.005, 0.086)	1.77 (0.14)
Cond*ISC				-0.28 (0.49)	(-1.25, 0.70)	-0.57 (0.83)

Note. All p values were corrected following the Benjamini-Hochberg procedure (** = p <0.01; * = p < 0.05; † = p <0.10).

Table A.3

Models predicting empathic accuracy by ROI (HbR) in the emotion rating task.

ROI (HbR)	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	-0.16 (0.24)	(-0.64, 0.31)	-0.69 (0.58)	-0.39 (0.40)	(-1.20, 0.41)	-0.97 (0.39)
Condition				0.033 (0.021)	(-0.009, 0.076)	1.55 (0.15)
Cond*ISC				0.36 (0.49)	(-0.63, 1.35)	0.72 (0.55)

DMPFC						
ISC	-0.30 (0.25)	(-0.80, 0.19)	-1.24 (0.58)	-0.47 (0.37)	(-1.21, 0.26)	-1.28 (0.36)
Condition				0.03 (0.02)	(-0.013, 0.073)	1.39 (0.17)
Cond*ISC				0.38 (0.49)	(-0.60, 1.37)	0.78 (0.55)
rTPJ						
ISC	0.38 (0.26)	(-0.14, 0.89)	1.47 (0.58)	0.72 (0.36)	(0.001, 1.43)	1.99 (0.12)
Condition				0.044 (0.021)	(0.002, 0.086)	2.11† (0.089)
Cond*ISC				-0.52 (0.51)	(-1.54, 0.50)	-1.02 (0.55)
lTPJ						
ISC	0.23 (0.24)	(-0.25, 0.70)	0.94 (0.58)	0.80 (0.33)	(0.16, 1.45)	2.47† (0.056)
Condition				0.048 (0.021)	(0.007, 0.089)	2.33† (0.089)
Cond*ISC				-1.14 (0.45)	(-2.05, -0.23)	-2.51† (0.051)
rTemporal						
ISC	0.15 (0.26)	(-0.35, 0.66)	0.61 (0.58)	0.29 (0.38)	(-0.46, 1.04)	0.77 (0.44)
Condition				0.039 (0.021)	(-0.004, 0.082)	1.83 (0.10)
Cond*ISC				-0.11 (0.51)	(-1.14, 0.91)	-0.22 (0.82)
lTemporal						
ISC	0.16 (0.24)	(-0.31, 0.63)	0.68 (0.58)	0.87 (0.32)	(0.24, 1.50)	2.74† (0.055)
Condition				0.043 (0.02)	(0.003, 0.08)	2.15† (0.089)
Cond*ISC				-1.33 (0.44)	(-2.20, -0.46)	-3.06* (0.022)
Visual						
ISC	0.13 (0.24)	(-0.34, 0.60)	0.56 (0.58)	0.41 (0.40)	(-0.039, 1.21)	1.03 (0.39)
Condition				0.041 (0.022)	(-0.002, 0.084)	1.88 (0.10)

Cond*ISC				-0.42 (0.49)	(-1.40, 0.56)	-0.87 (0.55)

Notes. All p values were corrected following the Benjamini-Hochberg procedure (** = p <0.01; * = p < 0.05; † = p <0.10).

Table A.4

Models predicting factual accuracy by ROI (HbR) in the story listening task.

ROI (HbR)	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	4.33 (17.23)	(-30.07, 38.73)	0.25 (0.88)	-11.39 (26.70)	(-64.70, 41.93)	-0.43 (0.86)
Condition				0.49 (1.66)	(-2.83, 3.82)	0.30 (0.99)
Cond*ISC				27.15 (35.24)	(-43.22, 97.52)	0.77 (0.67)
DMPFC						
ISC	-5.93 (18.13)	(-42.12, 30.25)	-0.33 (0.88)	-8.60 (25.11)	(-58.76, 41.55)	-0.34 (0.86)
Condition				0.36 (1.66)	(-2.95, 3.66)	0.22 (0.99)
Cond*ISC				5.52 (36.91)	(-68.19, 79.22)	0.15 (0.88)
rTPJ						
ISC	6.08 (24.31)	(-42.44, 54.60)	0.25 (0.88)	-49.59 (44.31)	(-138.08, 38.91)	-1.12 (0.86)
Condition				-0.016 (1.66)	(-3.34, 3.31)	-0.01 (0.99)
Cond*ISC				81.23 (53.14)	(-24.90, 187.35)	1.53 (0.67)
lTPJ						
ISC	-8.69 (18.83)	(-46.27, 28.89)	-0.46 (0.88)	-15.56 (26.40)	(-68.27, 37.16)	-0.59 (0.86)
Condition				0.27 (1.71)	(-3.14, 3.68)	0.16 (0.99)
Cond*ISC				13.59 (38.39)	(-63.09, 90.28)	0.35 (0.85)

rTemporal						
ISC	3.88 (19.76)	(-35.55, 43.32)	0.20 (0.88)	-10.66 (27.27)	(-65.13, 43.81)	-0.39 (0.86)
Condition				0.63 (1.69)	(-2.75, 4.01)	0.37 (0.99)
Cond*ISC				31.13 (40.04)	(-48.83, 111.08)	0.78 (0.67)
lTemporal						
ISC	-2.94 (19.59)	(-42.05, 36.17)	-0.15 (0.88)	-18.99 (29.35)	(-77.61, 39.61)	-0.65 (0.86)
Condition				0.012 (1.76)	(-3.51, 3.53)	0.007 (0.99)
Cond*ISC				28.72 (40.36)	(-51.87, 109.32)	0.71 (0.67)
Visual						
ISC	9.43 (20.01)	(-30.51, 49.36)	0.47 (0.88)	-3.92 (25.96)	(-55.77, 47.93)	-0.15 (0.88)
Condition				0.042 (1.68)	(-3.31, 3.39)	0.025 (0.99)
Cond*ISC				33.75 (41.89)	(-49.92, 117.43)	0.81 (0.67)

Notes. No region in either set of models shows main or interaction effects predicting factual accuracy during story retelling.

Table A.5

Models predicting factual accuracy by ROI (HbR) in the emotion rating task

ROI (HbR)	Main Effects Model			Interaction Model		
	β (SE)	**95% CI**	**t val (p)**	**β (SE)**	**95% CI**	**t val (p)**
MPFC						
ISC	-3.27 (17.95)	(-39.09, 32.55)	-0.18 (0.99)	3.29 (31.15)	(-58.91, 65.49)	0.92 (0.92)
Condition				0.50 (1.66)	(-2.82, 3.81)	0.30 (0.95)
Cond*ISC				-9.76 (38.40)	(-86.42, 66.90)	0.80 (0.80)
DMPFC						
ISC	29.50 (18.34)	(-7.10, 66.10)	1.61 (0.53)	3.57 (27.67)	(-51.67, 58.81)	0.13 (0.92)
Condition				0.24 (1.63)	(-3.02, 3.50)	0.15 (0.95)
Cond*ISC				48.48 (37.16)	(-25.72, 122.68)	1.31 (0.34)

rTPJ						
ISC	-15.59 (19.61)	(-54.73, 23.54)	-0.80 (0.60)	17.57 (27.61)	(-37.56, 72.70)	0.64 (0.74)
Condition				0.49 (1.62)	(-2.74, 3.72)	0.30 (0.95)
Cond*ISC				-66.75 (39.44)	(-145.49, 11.99)	-1.69 (0.33)
lTPJ						
ISC	17.81 (17.94)	(-18.00, 53.61)	0.99 (0.68)	25.09 (26.01)	(-26.84, 77.02)	0.97 (0.59)
Condition				0.56 (1.67)	(-2.76, 3.89)	0.34 (0.95)
Cond*ISC				-14.32 (36.38)	(-86.95, 58.30)	-0.39 (0.80)
rTemporal						
ISC	-27.59 (19.08)	(-65.67, 10.48)	-1.45 (0.53)	28.65 (26.88)	(-25.01, 82.31)	1.07 (0.59)
Condition				-0.010 (1.54)	(-3.17, 2.97)	-0.065 (0.95)
Cond*ISC				-106.02 (36.96)	(-178.81, -32.23)	-2.87* (0.039)
lTemporal						
ISC	19.14 (17.49)	(-15.76, 54.05)	1.09 (0.57)	33.63 (25.61)	(-2.65, 3.82)	1.31 (0.59)
Condition				0.58 (1.62)	(-17.51, 84.77)	0.36 (0.95)
Cond*ISC				-27.42 (35.38)	(-98.05, 43.21)	-0.78 (0.62)
Visual						
ISC	-0.27 (17.74)	(-35.67, 35.12)	-0.015 (0.99)	32.76 (30.49)	(-28.13, 93.64)	1.07 (0.59)
Condition				0.97 (1.66)	(-2.35, 4.29)	0.58 (0.95)
Cond*ISC				-50.06 (37.51)	(-124.96, 24.83)	-1.34 (0.34)

Notes. All p values were corrected following the Benjamini-Hochberg procedure (** = p <0.01; * = p < 0.05; † = p <0.10).

Appendix B: Chapter 3 Supplementary Materials

Story Transcript

So I'm going to be talking about an experience that I feel that I'll always remember. Um, I think it was probably last fall. So, I don't drive, or I don't have a car in the city, in Philadelphia, so I have a Zipcar membership. And, so I took the Zipcar to do the grocery store. And it was kind of like in the evening and the night, so by the time I got back, or I was heading back home, it was kinda dark and so I kinda lost my way and I ended up going, somehow getting on the bridge to New Jersey. And I guess like that area of New Jersey isn't the most, isn't the safest place, so I tried, like I eventually somehow found my way back to the tollgate. And then I realized I didn't have any cash on me. So I asked the security tollgate person if there was like an ATM where I could go to to get cash. So then he directed me to, some yeah some directions, he gave me some directions to like a liquor store or something that had like an ATM but then it was kind of, the directions were kind of confusing. So I was trying to follow it as the best or to the best of my ability. And it was leading me through some like shady like neighborhoods and it didn't look very safe to me but then eventually I saw a light coming out of one of the stores and it looked like it had the ATM, so I thought I was going the right way. So I decided to try to pull up and park, parallel park, in a street. And then I was about to get out, but then I saw like flashing lights behind me. And the flashing lights turned out to be a police car, so I thought I didn't do anything wrong so I just waited for the policeman to come to me and then he asked me if he knew that I guess the street that I went through was a one-way street and I was going the wrong way. So then, I told him I didn't know and like I guess he kinda figured that I looked out of place, and I looked lost so I told him like my situation and I('d) try to look for this liquor store with the ATM but I couldn't find it. And so then the police officer like took pity on me and he was like oh just follow me, follow my car and I'll lead you to the um the right liquor store with the right ATM. So, I followed his car and I got um I went to the liquor store or the ATM but then around the liquor store there were like some scary looking people outside and inside. So then the policeman was like just just go in and get the cash and I'll be right here waiting like so he was like you don't even need to lock your car just go in and get it and yeah don't worry about those people outside. So I went in and got my cash and I came back out and then, by now I'm totally lost as to where I exactly am and where how to get back to the tollgate. So then I guess the um police officer saw or uh saw how lost I looked, so he was like you don't know where the bridge is, right? So he took me he's like just follow my car and then he took me so then I followed his car and he took me to the bridge and yeah I thanked him tremendously profusely and yeah without him I don't think that I would've survived that night, er, and yeah. But, the funny thing is like I looked in my Zipcar and I found out that there was the um access pass I guess EZ pass or whatever the thing is that was already in the car so I didn't not, I didn't need to go and get cash at the ATM and go through all that trouble. If I'd just looked on my windshield mirror.

Length: 270 seconds

Word Count: 710

Factual Accuracy Rubric

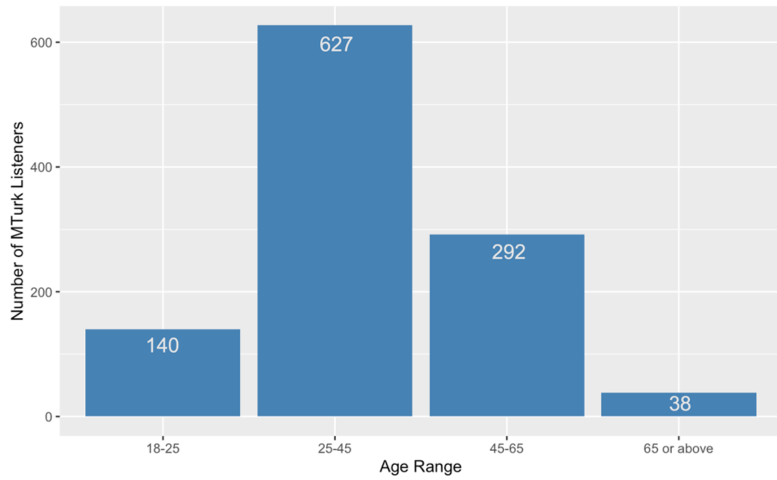
Table B.1: Coding Sheet. The following 50 facts and phrases were rated as either present (1) or absent (0) for each of the re-told stories. Facts were considered present if the information was mentioned at all, regardless of episodic placement or order. A single rater (the author) compiled factual accuracy ratings by listening to each story twice. Analysis was conducted using the overall coding sheet score, as well as separate sub-scores for the factual and phrase-based scales.

Item	Original Text	Factual Content or ***Exact Phrase*** (S = speaker)
1	"I feel that I'll always remember"	This was a memorable story for the speaker (S)
2	"Last fall"	The events occurred in the fall
3	"I don't have a car"	S did not have a car
4	"Philadelphia"	S lives in Philadelphia
5	"Zipcar"	S had a membership to Zipcar
6	"Grocery store"	S went to the grocery store
7	"In the evening and the night"	In the evening
8	"I was heading back home"	When S was heading back from the store
9	"it was kinda dark"	It was dark
10	"I kinda lost my way"	S got lost
11	"getting on the bridge"	S went across the bridge
12	"New Jersey"	To New Jersey
13	"isn't the safest place"	The area of NJ across the bridge didn't seem safe
14	"back to the tollgate"	S found her way to the tollgate
15	"security tollgate person"	There was an attendant at the tollgate
16	"ATM"	S asked for the location of an ATM
17	"gave me some directions"	The attendant gave S directions
18	"liquor store	To an ATM at a liquor store
19	"the directions were kind of confusing"	The directions were confusing
20	"trying to follow"	S tried to follow the directions
21	"to the best of my ability"	***Phrase***
22	"shady like neighborhoods"	S was driving in a neighborhood that seemed unsafe
23	"light coming out of one of the stores"	S saw a store with lights on
24	"parallel park"	S tried to park or parallel park by the store
25	"flashing lights"	S saw flashing lights

26	"police car"	A police car pulled up and the officer approached her
27	"I didn't do anything wrong"	S thought she didn't do anything wrong
28	"one-way street"	S was on a one-way street
29	"going the wrong way"	Traveling in the wrong direction
30	"I didn't know"	S didn't know she'd gone the wrong way on the street
31	"I looked out of place"	The officer noticed she was lost
32	"took pity on me"	***Phrase***
33	"'follow my car'"	The officer told S to follow him
34	"right liquor store"	To the right liquor store
35	"right ATM"	With the ATM
36	"scary looking people"	There were
37	"I'll be right here waiting"	The officer waited for S
38	"Don't even need to lock your car"	The officer told S not even to worry about locking her car
39	"Don't worry about those people"	The officer reassured S
40	"Got my cash"	S got cash from the ATM
41	"Get back to the tollgate"	S realizes she doesn't know how to get back to the tollgate
42	"You don't know where the bridge is"	The officer realizes S is still lost
43	"He took me to the bridge"	The officer leads S to he bridge
44	"tremendously profusely"	S thanked the officer
45	"survived that night"	***Phrase***
46	"The funny thing is"	***Phrase***
47	"Access pass, I guess EZ pass"	S found an electronic pass in the Zipcar
48	"Didn't need to get cash"	S could have gone through the toll without getting cash
49	"All that trouble"	***Phrase***
50	"If I'd just looked on my windshield mirror"	The EZ pass was located on the windshield

Figure B.1

MTurk Listener Age Distribution



Note. Count of listeners in each age range recruited on Mechanical Turk (n=1,097).

fNIRS Probe Design and Data Collection

fNIRS measures the relative concentration changes in oxygenated hemoglobin (HbO), deoxygenated hemoglobin (HbR) and total hemoglobin (HbT), within approximately 30mm of cortical tissue nearest to the skull, during functional tasks. fNIRS operates using optodes – laser or LED sources, emitting near-infrared spectrum light, and near-IR light detectors – placed into close-fitting caps (Ferrari & Quaresima, 2012). The caps for fNIRS recording were designed and constructed by the research team; two cap sizes, 56cm and 58cm, were constructed to fit a range of participant head sizes.

At the beginning of each recording session, each participant was measured for proper cap fit, the cap was placed onto the participant's head and a member of the research team placed all optodes in the cap. In a test recording, raw data were calibrated until the signal for all channels fell within the 80-120db range. Two methods were used to improve signal, manual manipulation of the optodes and gain setting. When channel signal fell outside of the required range, the researcher first attempted to adjust the optode-scalp contact for optodes in that channel. As a secondary measure, gains were reset across all 20 channels to improve the raw data range. Gain setting occurred no more than twice for any participant, to prevent degradation of the signal-to-noise ratio (SNR). Data were recorded at 50Hz; for the listening portion of the Retelling task, this produced 13,500 data points.

fNIRS Data Cleaning and Channel Selection

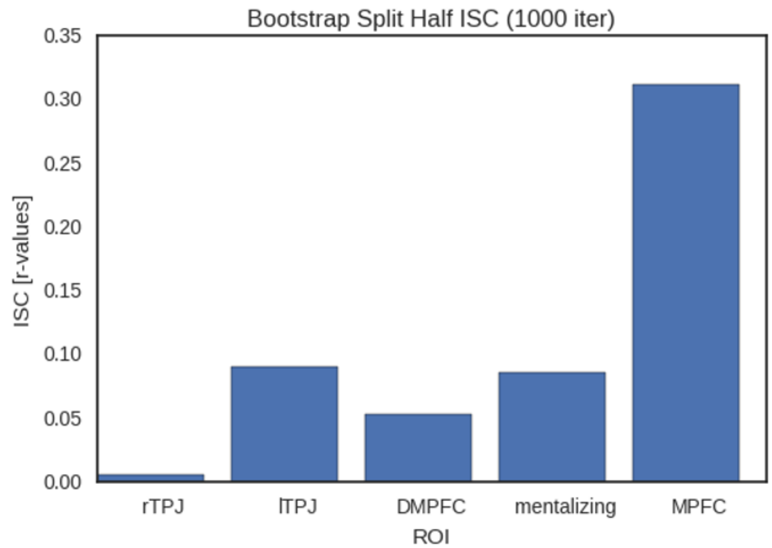
Before analysis, raw fNIRS data were visually checked for motion artifacts, the presence of cardiac waves and overall signal quality (SNR). Within each participant, channels were excluded if the SNR looked low or if large, clearly defined motion artifacts were present. The presence of 1Hz cardiac waves, a physiological indicator that the fNIRS channel was passing through cortical tissue, was an indicator of relatively good SNR. Per participant, the number of channels excluded ranged from zero to 15; 14 out of 36 participants had all channels included in the ISC analysis. Channels which remained after this manual exclusion were processed in HomER2 software with a bandpass filter, and converted to concentration units (μM; (Huppert et al., 2009). Included channels were then passed into an Jupyter Python notebook; intersubject correlation for story listening data were calculated in Python scripts written by the research team. Time series data in each channel were standardized and despiked and time points greater than three standard deviations or with a difference score greater than

0.2 were removed (set to NA). Finally, the data for each channel were down sampled (from 13,500 to 500 data points) before calculation of ISC.

Additional Results

Figure B.2

Split-half ISC by Region and System



Note. Split-half ISC by ROI, including the combined mentalizing ROI.

Table B.2

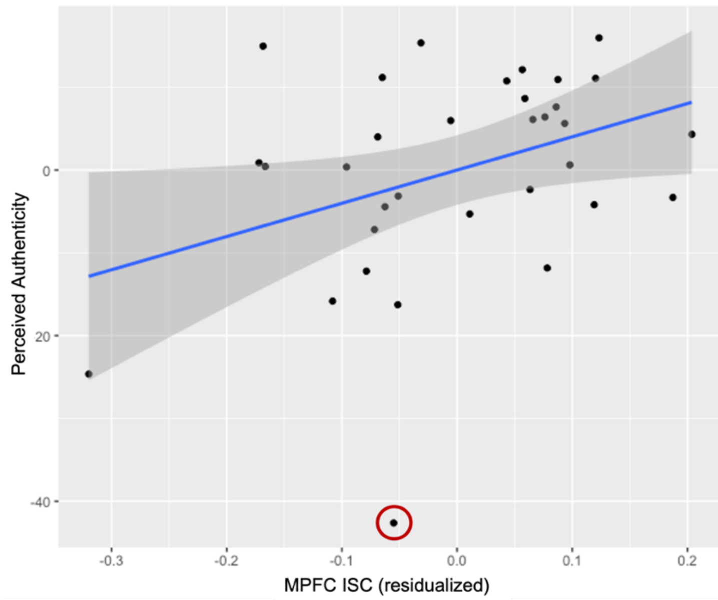
*Perceived Authenticity ~ β1*MPFC*$_{ISC}$ *+ β2*mentalizing*$_{ISC}$ *+ error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	61.771	2.647	23.334	<2e-16
MPFC	0.394	40.15	18.459	2.175	0.038*
mentalizing	-0.244	-29.28	21.78	-1.344	0.189

Note. Predicting the authenticity of the speaker in retelling by ROI, including one outlier (complete data set; df=30). Measure combines believability, realism and the speaker's trustworthiness ratings from MTurk ratings of story retellings (** = p <0.01; * = p < 0.05; † = p <0.10).

Figure B.3

One-to-rest ISC and perceived authenticity



Note. Outlier value – greater than 3 standard deviations below the mean – is included in this plot as the circled data point.

Regression Results at the ROI level

Table B.3

*Perceived Authenticity ~ β1*MPFC + β2*DMPFC + β3*rTPJ + β4*lTPJ + error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	62.614	3.000	20.874	<2e-16
MPFC	0.391	38.426	19.959	1.925	0.0657†
DMPFC	0.032	4.358	29.897	0.146	0.8853
rTPJ	-0.026	-3.390	31.190	-0.109	0.9143
lTPJ	-0.227	-28.098	35.112	-0.800	0.4311

Note. Predicting the authenticity of the speaker in retelling, by individual region (df=25). (** = p <0.01; * = p < 0.05; † = p <0.10)

Table B.4

*Speaker Appeal ~ β1*MPFC + β2*DMPFC + β3*rTPJ + β4*lTPJ + error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	40.464	2.363	17.122	2.55e-15
MPFC	0.453	36.376	15.726	2.313	0.0292*
DMPFC	-0.023	-2.583	23.555	-0.110	0.9136
rTPJ	-0.058	-6.237	24.574	-0.254	0.8017
lTPJ	-0.261	-26.322	27.664	-0.952	0.3505

Note. Predicting the engagement between the speaker and listener in retelling by individual region (df=25). Measure combines enthusiasm, likeability and similarity ratings from MTurk ratings of story retellings. (** = p <0.01; * = p < 0.05; † = p <0.10)

Table B.5

*Listener Experience ~ β1*MPFC + β2*DMPFC + β3*rTPJ + β4*lTPJ + error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.0	34.377	2.728	12.601	2.5e-12
MPFC	0.369	33.218	18.153	1.830	0.0792†
DMPFC	-0.147	-18.540	27.191	-0.682	0.5016
rTPJ	-0.057	-6.806	28.367	-0.240	0.8123
lTPJ	-0.128	-14.497	31.934	-0.454	0.6538

Note. Predicting the listener's experience of the story in retelling by individual region (df=25). Measure combines enjoyment and likelihood of retelling the story ratings from MTurk ratings of story retellings. (** = p <0.01; * = p < 0.05; † = p <0.10).

Table B.6

*Factual Accuracy ~ β1*MPFC + β2*DMPFC + β3*rTPJ + β4*lTPJ + error*

ROI	Standardized Coefficient	Coefficient	Standard Error	t-value	p-value
(intercept)	0.00	28.950	1.602	18.075	7.25e-16
MPFC	0.366	19.500	10.658	1.830	0.0792
DMPFC	0.205	15.302	15.964	0.959	0.3470
rTPJ	-0.154	-10.941	16.654	-0.657	0.5172
lTPJ	-0.106	-7.105	18.749	-0.379	0.7079

Note. Predicting factual accuracy in retelling, by individual region (df=25). (** = p <0.01; * = p < 0.05; † = p <0.10).

Table B.7

Correlation of Communication Scale Factors

	Perceived Authenticity	Speaker Appeal	Listener Experience
Perceived Authenticity	1		
Speaker Appeal	0.8539	1	
Listener Experience	0.834	0.9222	1

Table B.8

Correlation of ISC across all ROIs and the combined mentalizing system.

	MPFC	DMPFC	rTPJ	lTPJ
MPFC	1			
DMPFC	0.379	1		
rTPJ	0.139	0.049	1	
lTPJ	0.038	0.070	0.013	1
mentalizing	0.326	0.574	0.529	0.415

Appendix C: Chapter 4 Supplementary Materials

Screening Survey

Demographics

1. First Name
2. Last Name
3. Email address
4. Phone number
5. Age
6. Gender (Female/Male)
7. Ethnicity (African American/Black (not Latino(a)/Hispanic), Asian/Pacific Islander, Caucasian/White (not Latino(a)/Hispanic), Latino(a)/Hispanic, Middle Eastern, Native American/Alaskan Native, Other)
8. Zip code of current residence

fNIRS Eligibility

9. Are you right handed? (yes/no)
10. Do you speak English with equivalent fluency to a first language? (yes/no)
11. Do you have a history of any major health or mental health issues? (yes/no)
12. Do you have a history of stroke or other neurological disorders? (yes/no)
13. Have you taken any kind of psychotropic medications in the past 8 weeks? (yes/no)
14. Have you been diagnosed with post-traumatic stress disorder (PTSD)? (yes/no)
15. Have you been admitted to a psychiatric hospital within the past year? (yes/no)
16. How light/dark is your hair? (black, dark brown, medium brown or red, light to medium brown or red, light brown, dark blonde, medium blonde, light blonde, very light blonde/gray/white, other (i.e. green, blue, pink))
17. What length is your hair? (no hair, buzz cut, above shoulder, shoulder length, below shoulder)
18. How thick is your hair? (thin or fine, medium density, thick or coarse)

Education

19. Please select the education level you have completed:
 (less than high school, high school, some college, bachelor's degree, some graduate school, master's degree, doctorate or professional degree, unknown)
20. Please select the education level completed by your mother:
 (less than high school, high school, some college, bachelor's degree, some graduate school, master's degree, doctorate or professional degree, unknown)
21. Please select the education level completed by your father:
 (less than high school, high school, some college, bachelor's degree, some graduate school, master's degree, doctorate or professional degree, unknown)
22. Are you currently enrolled in a college or university? (yes/no)

23. Are you currently an undergraduate or graduate/professional student? (undergrad/grad)
24. What is/was your undergraduate major? (if applicable)
25. In your graduate/professional program, what is/was your major field of study? (if applicable)

Classification

26. How much would you like to attend…a dramatic play, a musical, a comedic play, a soccer game, a football game, a basketball game? (0-10)
27. I consider myself…(more of a theater fan, more of a sports fan, a fan of neither theater nor sports, equally a fan of both theater and sports)
28. Do you currently belong to any arts performance groups? (yes/no)
29. Do you currently belong to any sports teams? (yes/no)
30. In the last 12 months, how many times have you attended a live, professional or university theater performance in person? (0-7 or more)
31. In the last 12 months, how many times have you attended a live, professional or university sports event in person? (0-7 or more)
32. In the last month, how many times have you attended a live, professional or university theater performance in person? (0-7 or more)
33. In the last month, how many times have you watched a professional or university theater performance through some other media (e.g. TV, YouTube)? (0-7 or more)
34. In the last month, how many times have you attended a live, professional or university sports event in person? (0-7 or more)
35. In the last month, how many times have you watched a professional or university sports event through some other media (e.g. TV, YouTube)? (0-7 or more)

Recruitment Criteria:

Age = 18-30, inclusive
Gender = Female
Ethnicity = Any
Zip_code = Any

Right_handed = Yes
English = Yes
Health = No
Stroke_neuro = No
Psychotropic = No
PTSD = No
Psychiatric = No

Hair_color = 9 (very light blonde/grey/white) to 4 (light to medium brown/red), inclusive
    if Hair_color = 10 (other), read for eligibility (may need to call)
    if Hair_color = 3 (medium brown/red), HOLD scheduling, keep on waiting list
Hair_length = Any
Hair_density = Any

Educ = Any
Educ_Mother = Average with Educ_Father for SES; match sports fans and theater fans by age and SES
Educ_Father = See above for SES designation, with Educ_Mother
Educ_Enrolled (yes/no) = Any
Educ_UGG (undergrad/grad) = Any

Classification criteria:

Primary:

1. Preference for future events
2. Self-reported fan identification

Secondary:

3. Self-reported behavior in attending and viewing events
4. Group (university team, club, etc.) participation
5. Academic training, i.e. theater majors and sports kinesiologists

<u>Primary interest classification</u>
Based on

1. "How much would you like to attend…"
   THEATER_SUM = sum of scores (0-30) for drama, musical, comedy
   SPORT_SUM = sum of scores (0-30) for soccer, football, basketball
   If THEATER_SUM = SPORT_SUM – do not recruit
   If abs(THEATER_SUM – SPORT_SUM) < 10 – go to secondary classification
   If abs(THEATER_SUM – SPORT_SUM) > 10 – then
       If THEATER_SUM > SPORT_SUM = **Theater Fan**
       Else **Sports Fan**

AND

2. "I consider myself…"
   More of a theater fan = **Theater Fan**
   More of a sports fan = **Sports Fan**
   A fan of neither theater nor sports = Do not recruit
   Equally a fan of both theater and sports = Do not recruit

If classification based on 1 and 2 contradict each other, then

1) HOLD for recruiting until all strongly identifying (agreeing) participants have been recruited
2) As necessary, go to secondary classification

<u>Secondary classification</u>

3. **Recent Attendance** (month + year): If liking for theater and sports event are within 10 points, then frequency of attendance at theater and sports events, as well as media-based viewing of theater and sports through media (TV/YouTube, etc.) will be considered.

4. **Group Participation**: If frequency of attendance and viewing of theater and sports is roughly equivalent, then current group membership in a sports team or performing arts group will be considered. E.g. sports team members with (abs(THEATER_SUM – SPORT_SUM) < 10) will be classified as **Sports Fan**.

5. **Academic Training**: If the individual reports participation in both (or neither) theater and sports-related groups, or participation in neither type of group, then their academic background/major will be considered. E.g. theater or music majors with (abs(THEATER_SUM – SPORT_SUM) < 10) will be classified as **Theater Fan**

Promotional Video Development

All original promotional video footage was professionally produced and acquired from the public domain (i.e. YouTube) or materials licensed by the University of Pennsylvania for educational purposes (i.e. DigitalTheatrePlus). Out of the six promotional videos, four (theater: comedy and drama, sports: soccer and football) are edited versions of professionally constructed promos. The remaining two promotional videos (theater: musical and sports: basketball) were substantially created from full event footage. Taken together, all promotional videos are between 94 and 101 seconds in length (M=97.5s) and there is no difference between the length of theater (M=97.67s) and sports (M=97.33s) videos (t(5)=0.874).

Videos were edited to remove any intro and outro information (i.e. name of presenting/promoting organization), intertitle cards (i.e. title of play, name of director, name of team(s), team statistics), and quotes or other indicators from expert reviews. Excisions from the video track were replaced with continuous footage from the scene following the gap in the video track. A title card was added to the beginning of each video, with a standardized presentation of white text on a black background for each title. Title cards consisted of either the title of the play (i.e. "The Comedy of Errors") or the names of the teams playing (i.e. "Chelsea vs. Arsenal"). Voiceover narration was removed from each track, and existing music in the video was seamlessly looped to cover any gaps in the audio track.

After editing, each promotional video contains video and corresponding audio clips from the event, including scenes with character dialogue (in theatrical videos), or announcer narration/dialogue (in sports videos). Each video also contains musical accompaniment to the video footage, which acts as a background under dialogue scenes and as foregrounded sound for otherwise silent video clips. Voiceover narration was added to each video, recorded by the same (male) speaker. The narration scripts were constructed to (1) identify the play title or teams involved, (2) provide background on the featured characters or players, and (3) convey the tone of the event with positive adjectives. Adjectives were counter-balanced across the theater and sports categories, such that adjective pairs (e.g. riveting/remarkable, energetic/wild, dynamic/powerful) were used together in one video within each category. In the voiceover narration, mean word counts are equal across categories, at 63.333 words per video.

Promotional Video Scripts

Comedy: Comedy of Errors (WC = 65)

"Coming up, see the Royal Shakespeare Company production of The Comedy of Errors. In this widely-anticipated event, Richard Katz and James Tucker take on the roles of the twin brothers Antipholus of Syracuse and Antipholus of Ephesus, and their twin servants, the Dromios. This energetic play is a story of wild comic mishaps and mistaken identity, as the two sets of twins are finally reunited."

Drama: Kafka's Monkey (WC = 66)

"Coming up, see the Young Vic production of Kafka's Monkey. In this eagerly anticipated event, Kathryn Hunter takes on the role of Red Peter, a lecturer reminiscing about his former life as an ape and evolution into a human. This riveting play is a story of remarkable physical transformation told with incisive wit, as Red Peter realizes he has traded one form of captivity for another."

Musical: Sweeney Todd (WC = 59)

"Coming up, see the English National Opera production of Sweeney Todd.
In this long-awaited event, Bryn Terfel takes on the role of Sweeney Todd, the demon barber of Fleet Street. After losing his wife, daughter and freedom, Todd begins his bloody campaign for retribution. This dynamic play is a story of love, madness and a powerful drive for revenge."

Football: Los Angeles Rams vs. Dallas Cowboys (WC = 63)

"Coming up, see the Los Angeles Rams play the Dallas Cowboys.
In this widely-anticipated event, quarterback Kellen Moore and the NFC East champion Cowboys take on Jared Goff and the Rams. This dynamic game is the story of a powerful Cowboys team facing off against the rebooted Rams in their new LA home. Both teams are looking for a solid start this season."

Soccer: Chelsea vs. Arsenal (WC = 63)

"Coming up, see the Chelsea football club play Arsenal. In this eagerly anticipated event, Alexis Sanchez and twenty fifteen champions Arsenal take on Diego Costa and seven-time winners Chelsea in the FA Cup Final. This energetic game is the story of wild plays by two well-matched teams as they try to get a dominant win in the biggest game in the Premier League."

Basketball: Golden State Warriors vs. Boston Celtics (WC = 64)

"Coming up, see the Boston Celtics play the Golden State Warriors. In this long-awaited event, Isaiah Thomas and the Celtics takes on Klay Thompson and the Western conference-leading Warriors. This riveting game is the story of remarkable speed and skill, as Thompson makes his two hundredth three pointer of the season, and both teams play down to the buzzer for an early season win."

Promotional Video Norming Results

Results of the norming show some variation between the sports and theater categories, and across individual videos. Importantly, examining category-based ratings within fan groups, there are no significant differences in one of our main DVs for the dissertation (i.e., liking the clips, as operationalized by desire to see the first 10 minutes of the event), as well as excitement, engagement or the judged professionalism and audiovisual quality of the videos. There are differences in the emotion of the video, with sports fans rating sports events as less emotional than theater fans rate theater events. This may be explained by individual differences in emotionality on the part of sports and theater fans, or the perception that theater events are supposed to convey emotion while, in sporting events, emotion for the viewer is a byproduct of achievement (i.e., goals scored, etc.). Theater fans also rated the attractiveness of individuals in the theater videos lower than sports fans rated the attractiveness of individuals in sports videos. Two issues may be at work here; first, featured individuals in the sports promos are almost all male, while individuals in the theater promos are split between male and female and, in the case of the Drama video, include a female actor playing a male character. Since 87.5% of the MTurk participants identified as either heterosexual or bisexual, the weighting of male to female individuals in the sports events could account for the greater attractiveness rating for sports promos. It is also worth noting that in some cases in the theater promos, actors are made up as intentionally unattractive characters, also potentially influencing these results. See Table C.1 for full results.

When we examine the category-based ratings across the entire MTurk sample, significant differences in the overall interest in the videos and the judged professionalism of the video also appear (see Table C.2). The difference in overall interest may be attributable to the unbalanced sample sizes for the theater (N = 24) and sports (N = 14) fan groups. In an analysis with a randomly sampled subset of the theater fans (N=14), the difference in interest between the theater and sports events disappears (see Table 3). The difference in professionalism may be a result of conflating the professionalism of the video with the apparent professionalism of the production. Sports fans may have perceived one or more of the theater productions, with their use of minimal sets and costumes and/or warehouse-style venues, as not as not meeting their expectations of professionalism. When the results are restricted by fan group, as in Table C.1, this difference disappears, suggesting that theater fans recognize these as stylistic, aesthetic choices.

Across the six videos, theater and sports fans show differences in the Drama, Musical and Basketball videos. Excitement of the material differed significantly for the Drama and Musical promos, and marginally for the Basketball promo. Overall interest and the desire to watch the first 10 minutes of the event both differed for the Musical and Basketball promos, with people who were not fans of the event type significantly less interested in and willing to watch the event. The difference in overall interest and willingness to watch was also marginally significant for the Drama promo. The Drama promo showed a marginally significant idiosyncratic difference in its visual appeal. As a one-person show with a minimal set in a bare, warehouse-style venue, this difference might be attributable to the less complex style of the show itself, rather than the lighting, camera work or other aspects of the visual production of the promo. Likewise, the Basketball promo showed a significant difference in the engagement with the material; this appears to be due to an increase in sports fans' engagement over other sports videos, rather than a decrease in theater fans' engagement. See Table C.4 for full results.

	Mean (SD) Ratings for Congruent Interest by Category		
	Theater Fans - Theater Events	Sports Fans - Sports Events	T Test
Overall Interest	3.653 (1.31)	3.512 (1.33)	0.5878
Visual Appeal	3.403 (1.32)	3.634 (1.20)	0.3442
Sound: Actor/Announcer	3.931 (1.10)	3.610 (1.20)	0.1641
Sound: Background Music	4.083 (1.04)	4.073 (0.98)	0.959
Sound: Voiceover Narration	4.139 (1.10)	4.024 (0.91)	0.5533
Excitement	3.389 (1.33)	3.537 (1.21)	0.5479
Engagement	3.361 (1.26)	3.317 (1.11)	0.847
Emotion	2.917 (1.32)	**2.244 (1.02)**	**0.003165 ****
Attractiveness of Individuals	**2.639 (1.03)**	3.488 (1.03)	**<0.001*****
Professionalism	3.722 (1.07)	3.902 (0.97)	0.3643
Desire to see first 10 minutes	3.527 (1.44)	3.658 (1.42)	0.6418

Table C.1. Mean ratings for each of 11 measures within congruent groups (i.e. matching fan status and event type). Means in bold represent the lower rated category between the two groups. Differences exist for ratings of emotion, with sports fans rating sports events lower in emotion than theater fans rating theater events, and the attractiveness of individuals in the video. For attractiveness, theater fans rate individuals in theater event promos lower than sports fans rate individuals in sports promos.

	Overall Mean (SD) Ratings by Category		
	Theater Events	Sports Events	T Test
Overall Interest	3.408 (1.36)	**3.035 (1.39)**	0.04027*
Visual Appeal	3.208 (1.36)	3.398 (1.25)	0.2678
Sound: Actor/Announcer	3.933 (1.04)	3.796 (1.18)	0.3507

Sound: Background Music	3.975 (1.02)	4.097 (1.09)	0.3798
Sound: Voiceover Narration	4.092 (1.03)	4.027 (1.08)	0.6386
Excitement	3.083 (1.33)	3.168 (1.26)	0.618
Engagement	3.150 (1.23)	2.982 (1.30)	0.3148
Emotion	2.933 (1.29)	**2.142 (0.94)**	<0.001***
Attractiveness of Individuals	**2.633 (1.05)**	3.372 (0.99)	<0.001***
Professionalism	**3.567 (1.12)**	4.017 (0.94)	<0.001***
Desire to see first 10 minutes	3.250 (1.45)	3.159 (1.42)	0.6339

Table C.2. Mean ratings over all participants, collapsed across event categories. Means in bold represent the lower rated category. Significant differences overall exist for ratings of emotion, attractiveness of individualism and the perceived professionalism of the event promos.

	Overall Mean (SD) Ratings by Category, Balanced Samples		
	Theater Events	Sports Events	T Test
Overall Interest	3.179 (1.41)	3.088 (1.42)	0.6858
Visual Appeal	3.131 (1.37)	3.393 (1.29)	0.2103
Sound: Actor/Announcer	3.869 (1.12)	3.797 (1.28)	0.7055
Sound: Background Music	3.940 (1.10)	4.076 (1.17)	0.4493
Sound: Voiceover Narration	4.000 (1.06)	3.924 (1.15)	0.6631
Excitement	2.905 (1.33)	3.215 (1.29)	0.1338
Engagement	3.012 (1.28)	3.013 (1.30)	0.997
Emotion	2.893 (1.34)	**2.114 (1.01)**	<0.001***
Attractiveness of Individuals	**2.536 (1.07)**	3.468 (0.99)	<0.001***
Professionalism	**3.476 (1.18)**	3.911 (0.98)	0.01093*
Desire to see first 10 minutes	3.190 (1.50)	3.241 (1.49)	0.831

Table C.3. Mean ratings over all participants, collapsed across event categories, using a balanced number of participants in each of the fan types. Means in bold represent the lower rated category. Significant differences overall exist for ratings of emotion, attractiveness of individualism and the perceived professionalism of the event promos.

	Mean (SD) Ratings by Video											
	Comedy				***Drama***				***Musical***			
	All	Theater Fans	Sports Fans	T Test	All	Theater Fans	Sports Fans	T Test	All	Theater Fans	Sports Fans	T Test
Overall Interest	3.25 (1.35)	3.375 (1.38)	2.857 (1.29)	0.2545	3.1 (1.52)	3.417 (1.44)	2.429 (1.5)	0.0579	3.875 (1.09)	4.167 (0.96)	3.286 (1.14)	0.02295*
Visual Appeal	2.9 (1.29)	2.958 (1.33)	2.786 (1.31)	0.7003	2.85 (1.39)	3.167 (1.27)	2.286 (1.33)	0.0554	3.875 (1.15)	4.083 (1.10)	3.429 (1.23)	0.1111
Sound: Actor/Announcer	3.85 (1.08)	3.792 (1.14)	3.929 (1.07)	0.7135	3.7 (1.14)	3.75 (1.26)	3.571 (1.02)	0.6363	4.25 (0.84)	4.25 (0.85)	4.214 (0.89)	0.9044
Sound: Background Music	4.025 (0.77)	4.083 (0.83)	4 (0.68)	0.7394	3.575 (1.24)	3.792 (1.28)	3.214 (1.19)	0.1715	4.325 (0.89)	4.375 (0.92)	4.214 (0.89)	0.6013
Sound: Voiceover Narration	4.1 (1.01)	4.125 (1.03)	4.143 (0.86)	0.9549	4 (1.19)	3.875 (1.36)	4.142 (0.95)	0.4813	4.175 (0.87)	4.417 (0.83)	3.929 (0.73)	0.06849
Excitement	2.95 (1.26)	3.042 (1.30)	2.643 (1.15)	0.3342	2.475 (1.24)	2.917 (1.28)	1.786 (0.89)	0.002989***	3.825 (1.15)	4.208 (1.02)	3.071 (1.07)	0.003487***
Engagement	2.9 (1.17)	3.042 (1.19)	2.5 (1.02)	0.1489	2.85 (1.25)	3.125 (1.29)	2.429 (1.16)	0.09749	3.7 (1.11)	3.917 (1.14)	3.286 (1.07)	0.09748
Emotion	2.15 (1.08)	2.042 (0.91)	2.357 (1.39)	0.4571	3.15 (1.35)	3.292 (1.39)	2.857 (1.35)	0.3531	3.5 (1.06)	3.417 (1.18)	3.5 (0.85)	0.803
Attractiveness of Individuals	2.625 (0.89)	2.5 (0.93)	2.714 (0.83)	0.4678	2.075 (0.99)	2.208 (0.93)	1.929 (1.14)	0.4442	3.2 (0.97)	3.208 (0.98)	3.071 (0.99)	0.6841
Professionalism	3.075 (1.12)	3.167 (1.05)	2.857 (1.29)	0.4541	3.4 (1.15)	3.708 (1.08)	2.857 (1.03)	0.02236*	4.225 (0.73)	4.292 (0.81)	4 (0.55)	0.1966
Desire to see first 10 minutes	3.05 (1.43)	3.083 (1.47)	2.857 (1.41)	0.6419	2.75 (1.49)	3.125 (1.54)	2.214 (1.31)	0.06232	3.95 (1.26)	4.375 (0.88)	3.071 (1.44)	0.006331***

Table C.4. Mean rating by video, across all participants. Significant and marginally significant results are noted. In this analysis, difference between theater and sports fans are seen for the Drama, Musical and Basketball videos.

	Mean (SD) Ratings by Video, con't											
	Soccer				***Football***				***Basketball***			
	All	Theater Fans	Sports Fans	T Test	All	Theater Fans	Sports Fans	T Test	All	Theater Fans	Sports Fans	T Test
Overall Interest	2.75 (1.41)	2.583 (1.32)	3.071 (1.54)	0.3311	3.108 (1.47)	2.857 (1.42)	3.5 (1.40)	0.197	3.278 (1.28)	2.714 (1.27)	4 (0.82)	0.001089***
Visual Appeal	3.425 (1.26)	3.458 (1.22)	3.5 (1.29)	0.9224	3.351 (1.42)	3.143 (1.35)	3.714 (1.38)	0.2372	3.417 (1.08)	3.143 (1.11)	3.692 (0.95)	0.1349
Sound: Actor/Announcer	3.7 (1.14)	3.917 (1.14)	3.429 (1.16)	0.2181	4 (1.22)	4.190 (1.17)	3.786 (1.37)	0.3726	3.694 (1.19)	3.857 (1.24)	3.615 (1.12)	0.5618
Sound: Background Music	3.975 (1.07)	4.083 (1.18)	3.929 (0.92)	0.6549	4.324 (0.85)	4.571 (0.75)	4.071 (0.92)	0.1022	4 (1.31)	3.809 (1.44)	4.231 (1.17)	0.3571
Sound: Voiceover Narration	4.125 (1.07)	4.208 (1.10)	3.929 (1.07)	0.4489	4.054 (1.02)	4 (1.18)	4.143 (0.77)	0.6681	3.889 (1.17)	3.857 (1.28)	4 (0.91)	0.7068
Excitement	2.975 (1.25)	2.792 (1.10)	3.357 (1.39)	0.2067	3.189 (1.39)	3 (1.38)	3.5 (1.29)	0.2825	3.361 (1.13)	3.048 (1.20)	3.769 (0.93)	0.05877
Engagement	2.775 (1.31)	2.667 (1.34)	3 (1.24)	0.4443	3.027 (1.42)	2.857 (1.46)	3.286 (1.26)	0.3636	3.167 (1.16)	2.762 (1.30)	3.692 (0.63)	0.008938***
Emotion	2.225 (1.05)	2.083 (0.93)	2.357 (1.28)	0.4909	2.216 (1.06)	2.190 (1.08)	2.286 (1.07)	0.7988	1.972 (0.65)	1.857 (0.65)	2.077 (0.64)	0.3439
Attractiveness of Individuals	3.55 (1.04)	3.458 (1.06)	3.714 (1.07)	0.4816	3.162 (1.09)	3.238 (1.04)	3.286 (1.07)	0.8973	3.389 (0.80)	3.380 (0.74)	3.462 (0.97)	0.7995
Professionalism	3.975 (0.89)	4.125 (0.90)	3.786 (0.89)	0.2695	4.027 (1.04)	4 (1.05)	4 (1.11)	1	4.056 (0.89)	4.095 (0.89)	3.923 (0.95)	0.6046
Desire to see first 10 minutes	2.9 (1.39)	2.708 (1.33)	3.214 (1.53)	0.3128	3.189 (1.54)	2.857 (1.42)	3.785 (1.58)	0.08801	3.417 (1.32)	2.952 (1.32)	4 (1.08)	0.01745*

Table C.4. Continued from previous page.

fNIRS Montage

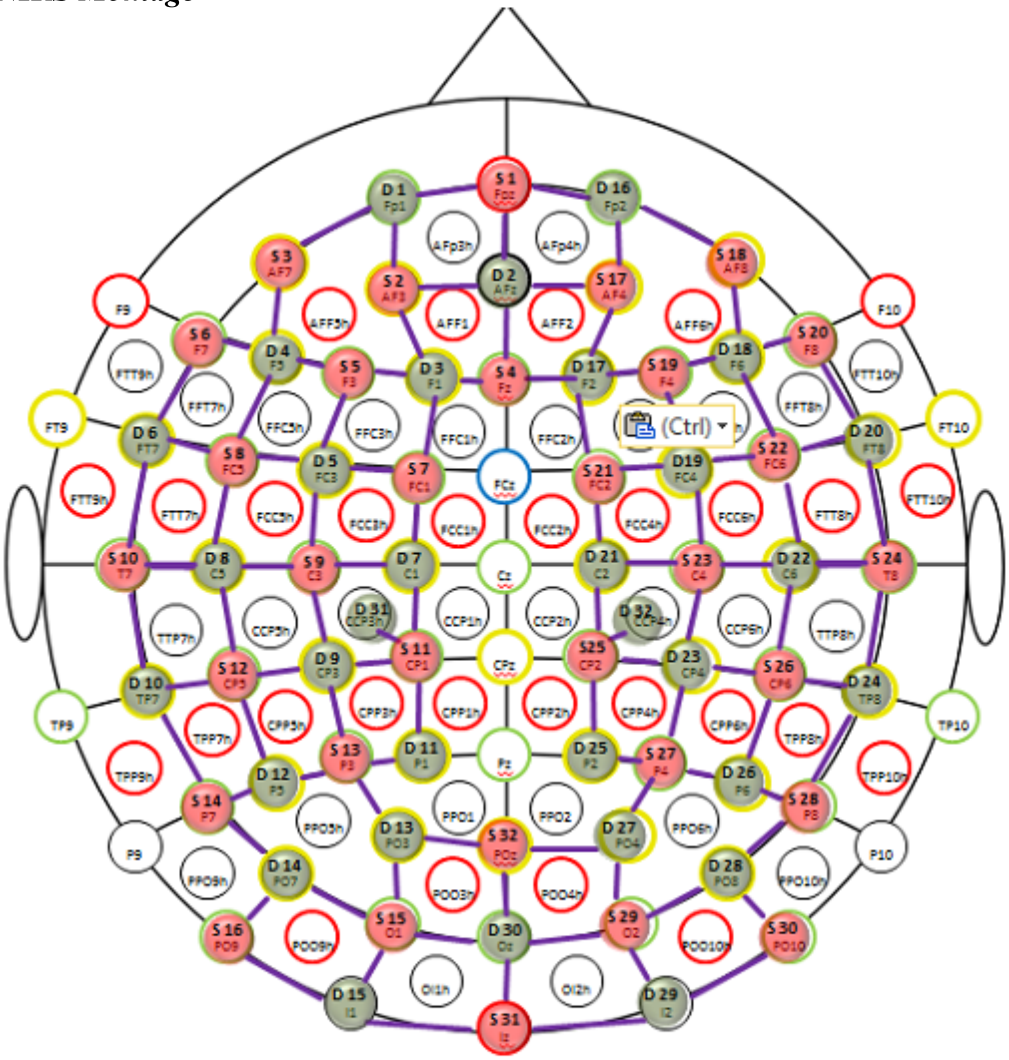


Figure C.1. fNIRS Montage on the International 10-20 system. Red icons represent source optodes, which emit near-infrared light at 760nm and 850nm (i.e. S1 = source 1). Green icons represent detector optodes, which measure photons after they pass through brain tissue (i.e. D1 = detector 1). Purple lines represent channels, where neighbor detectors are programmed to detect signal from neighboring sources. This montage contains 102 channels covering the MPFC, DMPFC, bilateral temporal regions, bilateral TPJs, visual cortex and other regions.

Additional Results

Table C.5

Main effect of dyad congruence on ISC (HbR) across all participants

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	-0.0022	0.0047	(-0.011, 0.007)	0.65
DMPFC	-0.0047	0.0046	(-0.014, 0.0044)	0.31
rTPJ	-5.76e-05	4.68e-03	(-0.0092, 0.0091)	0.99
lTPJ	9.71e-04	4.77e-03	(-0.0084, 0.010)	0.84

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_congruent + (1|s1_id) + (1|s2_id))

Table C.6

Descriptive statistics for ISC (HbR) in four regions of interest, across all participants

ROI (HbR)	*(Min, Max)*	*Median*	*Mean*
MPFC	(-0.15, 0.19)	0.0052	0.0066
DMPFC	(-0.13, 0.19)	0.0047	0.0072
rTPJ	(-0.16, 0.15)	0.0091	0.0052
lTPJ	(-0.14, 0.19)	0.0029	0.0046

Table C.7

Main effect of difference in composite liking scores on ISC (HbR) across all participants

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	1.99e-03	3.81e-03	(-0.0055, 0.0094)	0.60
DMPFC	-0.0017	0.0037	(-0.0093, 0.0056)	0.64
rTPJ	-0.0027	0.0037	(-9.9e-03, 0.0046)	0.47
lTPJ	-0.0027	0.0038	(-0.010, 0.0048)	0.49

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*score_diff + (1|s1_id) + (1|s2_id))

Table C.8

H2a: Main effect of video congruence across all participants

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	-0.0022	0.0047	(-0.011, 0.007)	0.65
DMPFC	-0.0047	0.0046	(-0.014, 0.004)	0.31
rTPJ	5.8e-05	4.6e-03	(-0.009, 0.009)	0.99
lTPJ	9.7e-04	4.8e-03	(-0.0084, 0.010)	0.84

Note. (ISC_{ROI} ~ ß0 + ß1*video_congruent + (1|s1_id) + (1|s2_id))

Table C.9

H2a: Main effect of video congruence for sports video stimuli

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	-0.0032	0.0063	(-0.019, 0.013)	0.70
DMPFC	0.0061	0.0071	(-0.007, 0.021)	0.40
rTPJ	-0.0037	0.0070	(-0.017, 0.010)	0.60
lTPJ	-0.0035	0.0077	(-0.017, 0.011)	0.66

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_group + (1|s1_id) + (1|s2_id)), within data for all sports videos, where dyad group represents pairs of either sports or theater fans.

Table C.10

H2a: Main effect of video congruence for theater video stimuli

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	-0.0012	0.0086	(-0.029, 0.005)	0.18
DMPFC	-0.0094	0.010	(-0.029, 0.01)	0.37
rTPJ	-0.0026	0.0089	(-0.020, 0.015)	0.78
lTPJ	-0.0036	0.0073	(-0.018, 0.010)	0.63

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*dyad_group + (1|s1_id) + (1|s2_id)), within data for all theater videos, where dyad group represents pairs of either sports or theater fans.

Table C.11

H2b: Main effect of video congruence for sports fans

ROI (HbR)	β	SE	CI	p (uncorrected, corrected)
MPFC	7.5e-03	7.2e-03	(-0.0066, 0.022)	0.29, 0.51
DMPFC	0.015	0.007	(0.0014, 0.029)	0.031*, 0.12
rTPJ	-0.0033	0.0074	(-0.018, 0.011)	0.66, 0.66
lTPJ	6.7e-03	7.6e-03	(-0.008, 0.021)	0.38, 0.51

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*video_cat + (1|s1_id) + (1|s2_id)), within data for sports fans, where video category represents sports or theater promotional videos.

Table C.12

H2b: Main effect of video congruence for theater fans

ROI (HbR)	β	SE	CI	p (uncorrected)
MPFC	1.4e-03	6.2e-03	(-0.011, 0.013)	0.83
DMPFC	2.1e-03	6.1e-03	(-0.0099, 0.014)	0.73
rTPJ	-0.0022	0.0061	(-0.014, 0.010)	0.71
lTPJ	5.9e-03	6.1e-03	(-0.006, 0.018)	0.33

Note. Regression: (ISC_{ROI} ~ ß0 + ß1*video_cat + (1|s1_id) + (1|s2_id)), within data for theater fans, where video category represents sports or theater promotional videos.

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