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Higher resting state functional connectivity between the vmPFC and rTPJ in individuals who display conversational synchrony

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ABSTRACT

The neural mechanisms that support synchrony of conversational behaviors (e.g., word production, turn length) are not well understood. Lesion work has suggested that the ventromedial prefrontal cortex (vmPFC) is important for noncontent speech convergence, which measures if word production becomes more similar across a conversation (Gordon, Tranel, & Duff, 2014). However, the relationship between neural activity and conversational synchrony has not been studied in healthy individuals and it is not known if differences in neural activity contribute to individual differences in conversational behavior. In this preliminary study, we assessed noncontent speech convergence in twenty female undergraduates who conversed with an unfamiliar conversational partner for 20 min. Ten dyads displayed noncontent speech convergence as they became more similar to one another in their production of words, while the other ten did not. Furthermore, we found higher resting state functional connectivity between the vmPFC and right temporoparietal junction (rTPJ) for the ten individuals in dyads who converged compared to those who did not converge. This provides complementary evidence for the importance of the vmPFC and rTPJ for conversational synchrony in healthy individuals and suggests that intrinsic neural network activity is related to individual differences in conversational synchrony.

1. Introduction

Successful communication requires that individuals synchronize and adapt their speech and other behaviors with those of their conversational partner. This coordination occurs at a variety of different levels, including adapting content and conversational topic, but also synchronizing noncontent aspects of conversation, including the amount of speaking time, gestures, linguistic style, and emotional expressions (Bernieri & Rosenthal, 1991; Cappella & Planalp, 1981; Giles, Coupland, & Coupland, 1991; Holler & Wilkin, 2011; Street, 1984). While there has been a large focus on understanding the downstream consequences of these forms of conversational synchrony, such as the development of rapport, social bonds, and empathy (Bernieri & Rosenthal, 1991; Giles et al., 1991), there has been less attention to the brain mechanisms that allow for communicators to easily pick up on and adapt their speech and other behaviors to that of their conversational partner.

Much of the contribution of neuroscience to this domain has been to describe the temporal synchrony of neural signals during communication tasks using fMRI (e.g., Stephens, Silbert, & Hasson, 2010) or EEG (e.g., Pérez, Carreiras, & Duñabeitia, 2017).

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Research has shown that areas of the brain, particularly those associated with speech comprehension and production, tend to become active at the same time in communicative partners (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012; Menenti, Pickering, & Garrod, 2012). However, the majority of these studies have not considered the brain regions or neural networks that might support synchrony of conversational behaviors (e.g., speaking time). As adapting even noncontent aspects of speech requires sensitivity to others' behaviors and altering one's own behavior, it seems likely that areas of the "social" brain that are also involved in complex processes like mentalizing and theory of mind may play a role (Wang & Hamilton, 2012). Furthermore, as there are individual differences in social ability in the healthy population (Dodell-Feder, Lincoln, Coulson, & Hooker, 2013), intrinsic activity of these brain regions may also contribute to individual differences in the ability to synchronize behavior in conversation.

Many previous neuroimaging studies are limited in how communication is characterized, as it is difficult for participants to have ecologically valid face-to-face conversations in the fMRI scanner. As a result, communication often takes the form of monologue (e.g., Stephens et al., 2010), or is restricted in some way (e.g., use of gestures only, Schippers et al., 2010). However, real-world conversation involves rich, dynamic interactions between individuals in which the contributions and behaviors of each person are tightly intertwined with those of their partner. Furthermore, many neuroimaging studies have focused on the contributions of brain areas that are involved actively during the task, but there is also important information to be learned about the organization of neural networks involved in the intrinsic connectivity of the brain at rest (Yeo et al., 2011), and how they relate to complex real world social behavior.

Therefore, the current study is a preliminary analysis using resting state functional connectivity (rsFC) to explore the neural networks that contribute to synchrony of conversational behaviors in unrestricted ecologically valid face-to-face social interaction. rsFC measures the temporal correlation of the hemodynamic fMRI signal between spatially segregated regions of the brain at rest (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995; Fox & Raichle, 2007). A large body of research suggests that these intrinsic networks identified at rest are related to a variety of cognitive and behavioral processes (e.g., empathy, executive control) (Cox et al., 2012; Hampson, Driesen, Skudlarski, Gore, & Constable, 2006; Seeley et al., 2007). For the purposes of studying the neural networks related to conversational synchrony, rsFC is an ideal tool as it allows for assessment of intrinsic functional brain connectivity while preserving the ecological validity of conversation, which occurs outside of the scanner. Indeed, research suggests that rsFC provides important information about the fundamental organization of the brain distinct from task-related functional connectivity (Yeo et al., 2011).

One critical region known to support aspects of conversational synchrony is the ventromedial prefrontal cortex (vmPFC). Individuals with damage to the vmPFC were consistently impaired in their ability to display conversational synchrony, as measured by noncontent speech convergence of words, with their conversational partner (Gordon et al., 2014). Noncontent speech convergence is independent of the topic or content of conversation, and characterizes the coordination of dialogue at a basic level by measuring whether or not participants become more similar to one another in the number of words they produce across a conversation (Street, 1984). Specifically, individuals with damage to the vmPFC were more likely to dominate conversations, suggesting an inability to adaptively alter their conversational productions with their communication partner. Likewise, a follow-up study found that some individuals with traumatic brain injury (TBI), a condition that commonly affects the integrity of the vmPFC, also showed disruptions in noncontent speech convergence (Gordon, Rigon, & Duff, 2015).

The vmPFC is involved in many aspects of social behavior, including empathy, understanding social cues, and aspects of theory of mind (Mah, Arnold, & Grafman, 2004; Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Stone, Baron-Cohen, & Knight, 1998). When considering other areas of the brain that may be implicated in conversational synchrony, other brain regions involved in similar mentalizing behaviors that have been shown to have high functional connectivity with vmPFC are likely candidates (Lombardo et al., 2010). In particular, the right temporoparietal junction (rTPJ) is involved in aspects of social behavior including perspective taking, theory of mind, and moral judgments (Aichhorn, Perner, Kronbichler, Staffen, & Ladurner, 2006; Saxe & Wexler, 2005; Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). It has also been implicated in behaviors related to conversational synchrony such as imitation and mimicry (Sowden & Catmur, 2015; Spengler, von Cramon, & Brass, 2010). High functional connectivity between rTPJ and vmPFC is associated with processing communicative intentions and perspective-taking (Tettamanti et al., 2017). In many cases, these findings are often specific to the right TPJ, as the left TPJ has been shown to have broader functions beyond social behavior (Perner, Aichhorn, Kronbichler, Staffen, & Ladurner, 2006; Saxe & Wexler, 2005).

Beyond rTPJ, there are other "core" brain regions involved in theory of mind, such as inferior frontal gyrus or precuneus, however, these areas seem to be more related to mirror systems, emotion, and mental imagery respectively (Molenberghs, Johnson, Henry, & Mattingley, 2016; Schurz, Radua, Aichhorn, Richlan, & Perner, 2014). Indeed, Wang and Hamilton (2012) have hypothesized that the mPFC and TPJ are critical for mentalizing aspects of mimicry, while the mirror neuron system is more involved in the visuo-motor aspects of mimicry. As conversational synchrony does not involve direct motor mimicry, we hypothesize that the role of the mPFC and TPJ is the most important. Furthermore, conversational synchrony, particularly for noncontent speech variables, is likely a more basic process than higher-order theory of mind, as noncontent speech convergence measures if participants are simply becoming more similar in the amount of speaking time. Indeed, in a meta-analysis of functional imaging studies, Decety and Lamm (2007) concluded that the rTPJ may be involved in lower-level cognitive processes requiring comparison between self-produced and external environments that then support more complex processes like theory of mind. This ability to compare self- and other-behavior may be a platform for conversational synchrony as well, as it requires recognizing a partner's behavior and adapting one's own speech productions in response. Furthermore, the mPFC and rTPJ are both known to have roles in self-other processing, and high functional connectivity between these two structures has been found when making self and other judgments, with evidence that the vmPFC is more involved in self-referential processing, while the rTPJ has a greater role in considering others (Lombardo et al., 2010). Similarly, Brennan, Galati, and Kuhlen (2010, pp. 301–344) hypothesize that speech coordination involves mPFC and rTPJ because of their known roles in partner-adapted processing.

While previous lesion research has begun to elucidate the role of the vmPFC in conversational synchrony (Gordon et al., 2014), the relationship between these potential neural substrates and conversational synchrony has not been studied in healthy individuals. Furthermore, it is not clear how much individual difference there may be in conversational synchrony in the healthy population and what factors may influence the likelihood that an individual displays conversational synchrony. Finally, although the individual contributions of the vmPFC and rTPJ have been well described for social functioning, the relationship and functional connectivity between the vmPFC and rTPJ has not been as well explored. In this study, we explore the relationship between resting state functional connectivity of the vmPFC and rTPJ with noncontent speech convergence in conversation, predicting that those individuals who display noncontent speech convergence will have higher rsFC between these brain regions. By examining noncontent speech convergence, we are able to look at a very basic form of synchrony that may be less likely to rely solely on speech production and comprehension areas of the brain (e.g., Hasson et al., 2012). Furthermore, rather than being limited by the unnatural forms of communication that are feasible in the fMRI scanner, we are able to assess conversational behavior with high ecological validity by examining naturalistic conversations that occur outside of the scanner in relationship to rsFC.

2. Methods

2.1. Participants

Twenty female undergraduate students at the University of Iowa participated in the study. We recruited female participants because the sex composition of the dyad is known to interact with convergence (Bilous & Krauss, 1988). By using all female participants, we were able to maintain the same conversational partner and same-sex dyads across all sessions. Furthermore, while we acknowledge that this might reduce the generalizability of our findings, we wanted to keep the sample as homogenous as possible, so that any findings in the sample more likely due to individual differences in brain-behavior relationships rather than confounding variables like sex, age, or education. All participants were native English speakers, and were screened during the recruitment phase to ensure: 1) MRI scanner compatibility; 2) right handedness; 3) no current or past neurological, psychiatric or cardiovascular conditions; 4) no history of learning disorders, 5) no use of medications affecting the central nervous system for 6 months preceding study, and 6) age between 20 and 23. Participants' mean age was 20.95 (SD = 0.89), and education ranged from 12 to 16 years (M = 14.1 SD = 1.12). Participants signed an informed consent prior to testing and were compensated for their participation. All study procedures were approved by the Institutional Review Board of the University of Iowa.

2.2. Conversational sample

Conversational samples were collected from each participant within the context of a larger battery of behavioral and neuropsychological assessments. The samples were collected using the instructions for the conversational section of the Mediated Discourse Elicitation Protocol (MDEP), designed to collect ecologically valid discourse samples in clinical or laboratory environments (Hengst & Duff, 2007). Participants were instructed to have a conversation, just as they might with anyone in everyday life. For all sessions, the conversational partner was a female undergraduate student at the University of Iowa, and she was instructed to converse with participants for approximately 20 min. She was blind to the hypotheses of the study and was not given any instruction or formal training for the conversation (e.g., not told what to talk about or how much to talk), but was encouraged to keep the conversation flowing and to wrap it up as smoothly as possible after about 20 min.

2.3. Transcription and coding

Each conversation was videotaped and transcribed following previous procedures (Duff, Hengst, Tranel, & Cohen, 2008). First, one research assistant (the original transcriber) transcribed the videotaped interaction verbatim. Then, the original transcriber rewatched the video with a second research assistant (the consensus transcriber). Together, the original and consensus transcriber made any necessary changes to the transcript to generate a final, consensus transcript.

Consensus transcripts were coded to determine the number of words and interactional turns. Interactional turn boundaries were defined by a change in speaker. If both partners spoke simultaneously, each speaker's utterance was counted as an interactional turn. Reliability checks for word- and turn-coding were performed on 15% of the dataset. Intra-rater agreement was 93% for turns and 99% for words. Inter-rater agreement was 94% for turns and 98% for words.

2.4. Noncontent speech convergence analysis

Conversational synchrony was quantified using noncontent speech convergence, following previous work (Gordon et al., 2014, 2015). Each conversation was divided in segments of approximately 60 s, while respecting previously coded turn boundaries. The percent difference between the participant and partner's production of words was calculated for each segment, corrected for the exact length of the segment, and averaged over the first fourth and the last fourth of the interaction. Dyads were categorized as those that did or did not display convergence following previous methods (Gordon et al., 2015). If the relative difference between the participants' productions became more similar across the conversation, those dyads were categorized as displaying convergence (e.g., Participant A produced 45% more words than their partner in the first fourth of the conversation, and only 10% more words in the last fourth). Dyads that converge are expected to have negative values when comparing the percent difference in the last fourth minus the percent difference in the first fourth, reflecting a decrease in the difference of their productions (e.g., 10%–45% = −35%). If the participants' relative productions became more dissimilar across the conversation, they were categorized as having not displayed convergence (e.g., Participant B produced 30% more words than their partner in the first fourth of the conversation, and 42% more words in the last fourth). Dyads that did not display convergence are expected to have positive values when comparing the percent difference in the last fourth minus the percent difference in the first fourth (e.g., 42%–30% = 12%). Note that the dyads did not differ in the length of the first fourth (Converging Dyads M = 5:22 min:sec, Non-converging Dyads M = 5:19; T(18) = 0.34, p = 0.73) and last fourth of their interaction (Converging Dyads M = 4:47 min:sec, Non-converging Dyads M = 4:48; T(18) = 0.07, p = 0.94) based on whether they displayed convergence.

2.5. Functional imaging data acquisition

All neuroimaging data were collected during a single session carried out at the University of Iowa Magnetic Resonance Facilities, on a 3 T whole-body MRI scanner (Magnetom TIM Trio, Siemens Healthcare, Erlangen, Germany) operated with a 12-channel RF head receive coil. High resolution T1-weighted brain images were acquired using a 3D Magnetization Prepared Rapid Gradient Echo Imaging (MPRAGE) protocol with 208 contiguous coronal slices, echo time (TE) = 3.04 ms, repetition time (TR) = 2530 ms, field of view (FOV) = 256mm2, voxel size = 1mm3 and flip angle = 10°. T2*-weighted resting state data were collected with a fast echo planar imaging (EPI sequence) with BOLD contrast (12 min, TR = 2000 ms, TE = 30 ms, 31 slices acquired in ascending order, voxel size = 3.4 × 3.4 × 3.5 mm, 64 × 64 matrix, flip angle = 75°). During resting state data collection, all participants were instructed to keep their eyes closed and let their mind wander without falling asleep.

2.6. Resting state data analysis

fMRI data preprocessing was carried out using FSL 5.0.4 (Smith et al., 2004) (See SI). EPI data were motion corrected, brain extracted, field map corrected and spatially smoothed (FWHM = 6.0 mm). Functional data was denoised using single-subject ICA, temporal filtering ($0.008 < f < 0.1$ Hz), nuisance regression (motion parameters, white matter, CSF, and global signal) and a final step of motion scrubbing (Power, Barnes, Snyder, Schlaggar, & Petersen, 2012). Nonlinear registration was used to transform the MPRAGE to standard MNI 2-mm space, and registration of the functional EPI to the MNI 2-mm template was carried out with the boundary-based registration (BBR) algorithm (Greve & Fischl, 2009). The two resulting transformations were concatenated and applied to the original EPI data to transform it into standard MNI space.

Regions of Interest (ROIs) were selected based on our hypotheses that the functional connectivity between the vmPFC and the rTPJ would be stronger in those who converge. The vmPFC coordinates were selected based on the area of maximal lesion overlap in the lesion patients who participated in Gordon et al., 2014. These coordinates (MNI coordinates = 10, 52, 2) were reported in Phillipi et al. (2012). The rTPJ ROI (MNI coordinates = 56, −56, 18) was selected based on a meta-analysis of theory of mind related fMRI studies (Schurz et al., 2014). All analyses run for the rTPJ ROI were also run for a left temporoparietal (lTPJ) ROI (MNI coordinates = −50, −58, 24). As activity in lTPJ is not specific to social behavior (Perner et al., 2006), the lTPJ was used as a control region, in order to examine whether the relationship with the vmPFC was specific to the rTPJ. ROI analysis was carried out in native space, and the resulting ROI correlation map was transformed into MNI space. Voxel-wise Pearson coefficients were computed between the corrected average timeseries extracted from a given ROI and the corrected timeseries for each voxel in the brain; the resultant statistical maps were transformed to Fisher's Z-scores (Zar, 1996). An ordinary least-square regression was performed to compare rsFC between each ROI and the whole brain between the two groups (convergers and non-convergers). Group-level ROI correlation statistical maps were thresholded at $Z > 3.1$, with a cluster significance of $p < 0.05$. After visual inspection, anatomical labels were assigned by referencing the Harvard-Oxford Cortical and Subcortical Structural Atlases in the FSL analysis package (Desikan et al., 2006; Eickhoff et al., 2007). To examine group differences in the rsFC between the vmPFC and the left and right TPJ ROIs we carried out one-tailed independent sample t-tests, with the hypothesis that individuals in dyads who converged would show higher levels of rsFC between only the rTPJ and vmPFC regions.

2.7. Other behavioral measures

During the test session participants were administered other surveys: (1) the Positive and Negative Affective Scale (PANAS) (Watson, Clark, & Tellegen, 1988), to assess their mood at the time of testing; the 20 PANAS items were evenly divided into positively and negatively valenced items, and then averaged together to obtain a positive affect score and a negative affect score for each participant; (2) the Reading part of the Wide Range of Achievement Test (WRAT) (Wilkinson, 2006), which strongly correlates with IQ (Ahles et al., 2003; Johnstone, Callahan, Kapila, & Bouman, 1996), and was used as an estimate of IQ to ensure that participants fell within the normal range; and (3) the 50 item version of the International Personality Item Pool (IPIP) representation of the Goldberg markers for the big-five factor structure (Goldberg, 1992), which allowed us to measure each participant's personality traits and to obtain scores for each of the five factors: agreeableness, conscientiousness, extraversion, neuroticism and openness to experience.

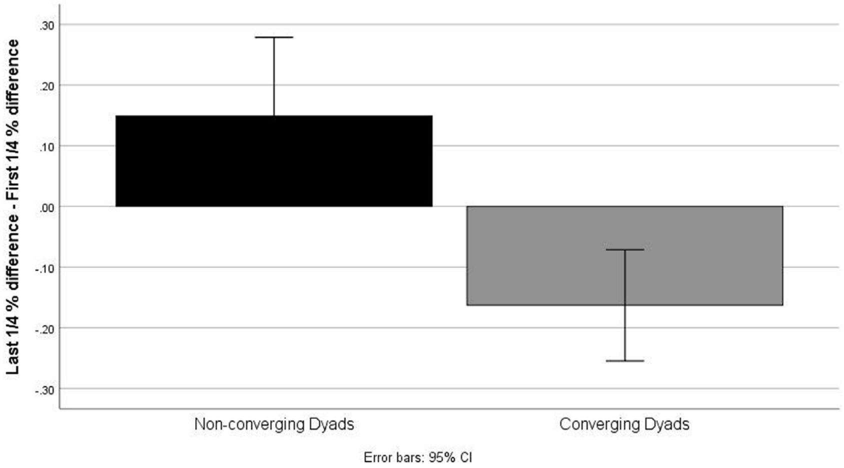

Fig. 1. Dyads who became more similar in their productions across time (last ¼ % difference-first ¼ % difference = negative value) were categorized as converging dyads, while those dyads that become more dissimilar in their productions were categorizes as non-converging dyads.

3. Results

3.1. Noncontent speech convergence

Across the 20 dyads, 10 dyads displayed convergence as the partners became more similar to one another in their production of words. Specifically, convergence was assessed by looking for a decrease in the difference between their productions in the last fourth, compare to the first fourth (resulting a negative value when subtracting last ¼ % difference – first ¼ % difference). As such, there is significant difference between groups, because the two groups differed in the direction in which their productions changed over time (see Fig. 1; T(18) = 4.44, $p < 0.0001$, 95% CI [0.164, 0.459]). Considering the dyad as a whole, there was, on average, a 24.92% difference in production of words in first fourth of the interaction, to only a 8.67% difference in the last fourth of the interaction. The other 10 dyads did not display convergence as the partners became more dissimilar to one another. Considering the dyad as a whole, there was, on average, an 8.65% difference in production of words in first fourth of the interaction, to a 23.55% difference in the last fourth. However, the degree to which the productions of the two groups changed over time (regardless of direction) did not differ (M = 16.25%, SD = 12.9% convergence vs. M = 14.9%, SD = 18.1% divergence, T(18) = 0.192, p = 0.85, 95% CI [-0.161, 0.135]). This suggests that the conversations did not fundamentally differ in the relative contributions of the partners, but differed in direction of the change over time. In order to insure that order of data collection did not affect the likelihood of displaying convergence, we looked at which sessions displayed convergence relative to when the data were collected. We noted that convergence occurred in 5 of the first 10 sessions collected and in 5 of the last 10 sessions collected.

3.2. Resting state functional connectivity

Whole-brain exploratory analyses revealed no significant group differences in rsFC between the vmPFC, rTPJ, or lTPJ and the rest

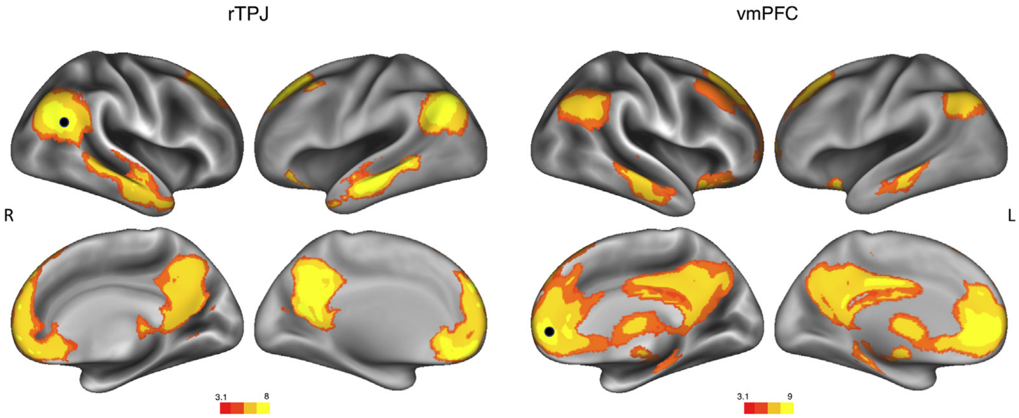

Fig. 2. Resting state functional connectivity maps across both groups for the right temporoparietal junction (rTPJ) and ventromedial prefrontal cortex (vmPFC) ROIs. The ROIs are indicated in black. Maps were thresholded for $Z > 3.1$, cluster $p < 0.05$.

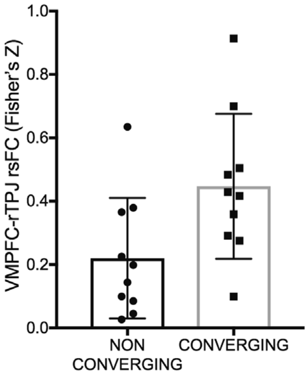

Fig. 3. Individuals who displayed noncontent speech convergence with their conversational partner (converging) had significantly higher resting state functional connectivity (rsFC) between the ventromedial prefrontal cortex (vmPFC) and the right temporoparietal junction (rTPJ) than those who did not display convergence (non-converging).

of the brain. Fig. 2 shows resting state functional connectivity maps across both groups for the ROIs. When we examined group differences in connectivity between the vmPFC and rTPJ, we found that the 10 individuals in dyads who converged showed, on average, higher rsFC between these two regions than those who did not converge (T(17.99) = -2.36, p = 0.01, d = 1.06, 95% CI [-0.46, −0.03]) (Fig. 3). There was no significant group difference in rsFC between the vmPFC and lTPJ (T(16.72) = -0.05, p = 0.96, 95% CI [-0.24, −0.23]).

Further analyses suggest that there was no correlation between the degree to which they converged or diverged (based on last ¼ % difference – first ¼ % difference shown in Fig. 1) and vmPFC-rTPJ connectivity, *r*(20) = -0.23, *p* = 0.32. Instead, those individuals that displayed convergence had higher levels of rsFC than those individuals who did not display convergence (Fig. 3). Additional control analyses showed that the two groups (10 individuals in dyads who converged vs. 10 individuals in dyads who did not converge) were not significantly different for mean relative head motion (T(17.99) = -0.52, p = 0.61, 95% CI [-0.04, 0.02]), mean absolute head motion (T(16.65) = 1.12, p = 0.28, 95% CI [-0.06, 0.18]), or signal-to-noise ratio (T(17.44) = -1.45, p = 0.16, 95% CI [-11.02, 2.02]).

3.3. Group differences on demographics factors and other behavioral measures

There were also no significant group differences for age, education, or WRAT scores used as a proxy for IQ. Furthermore, the participants reported similar scores on both the positive and the negative scale of the PANAS, as well as on all 5 personality traits examined (Table 1).

4. Discussion

In this preliminary study, we sought to explore the relationship between resting state functional connectivity (rsFC) and conversational synchrony, or the ability to synchronize and adapt speech and other behaviors in conversation. We found higher rsFC between the ventromedial prefrontal cortex (vmPFC) and the right temporoparietal junction (rTPJ) in individuals who displayed noncontent speech convergence of word production during conversation. This study provides complementary evidence for the importance of these brain regions for conversational synchrony in healthy individuals, building off previous lesion work analyzing the behavior of individuals with damage to the vmPFC (Gordon et al., 2014). Moreover, the relationship between vmPFC and the TPJ was specifically found for right TPJ, not left TPJ, which has not been as strongly implicated in social behavior (Perner et al., 2006). The vmPFC and rTPJ are typically associated with higher order aspects of social cognition, including theory of mind and moral decision-making (Saxe & Wexler, 2005; Stone et al., 1998; Young et al., 2010), and these results suggest that they may also play a role in a more fundamental ability to perceive and adaptively alter verbal output in response to a social partner. Noncontent speech convergence is a basic, often nonconscious process, and may be a building block for other higher-order aspects of social cognition like perspective taking and theory of mind. Although we did not directly measure the relationship between conversational synchrony and theory of mind in communicative contexts, the potential relationship between these aspects of communication and social behavior should be explored in the future.

In general, conversational synchrony has been shown to be related to higher perceptions of rapport and social affiliation among conversation partners (Bernieri & Rosenthal, 1991; Giles et al., 1991), however it is less clear how often it occurs in everyday social interactions without an explicit goal to affiliate. In our small sample, we found considerable individual variability in noncontent speech convergence, with 10 participants successfully displaying convergence, while the other 10 did not. Furthermore, these individual differences could not be explained by measures of personality (e.g., extraversion) or mood, as there were no significant group differences on any demographic or behavioral variables measured (Table 1). Of the variables we measured, the only difference we found between these two groups was on the rsFC of the vmPFC and rTPJ. Although there are likely other factors not measured here, this study suggests that intrinsic neural network activity may impact conversational behavior and provides an avenue for

Table 1

There are no statistically significant differences in demographics, estimate of IQ (using the WRAT), personality, or mood (using the PANAS) between individuals who displayed noncontent speech convergence (convergers) and those that did not (non-convergers).

	Age	Education	WRAT	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness to Experience	PANAS (positive)	PANAS (negative)
Non-convergers	20.9 (0.99)	14.1 (1.2)	105.7 (9.79)	23.4 (9.35)	33.1 (3.78)	28.8 (5.29)	24.4 (6.22)	27.2 (6.96)	27.2 (6.41)	11.7 (1.06)
Convergers	21 (0.82)	14.1 (1.1)	107.1 (9.73)	27.1 (6.64)	34.6 (4.27)	30.1 (6.49)	25.1 (8.39)	27.1 (5.22)	29.2 (5.59)	13 (4.14)
P Value	.81	1	.8	.32	.41	.63	.84	.97	.47	.36

Note: WRAT = Reading part of the Wide Range of Achievement Test; PANAS = Positive and Negative Affective Scale.

further exploration. This is in line with other research suggesting that differences in functional connectivity of brain structures contribute to individual variability on measures like empathy and social attachment (Cox et al., 2012; Rigon, Duff, & Voss, 2016).

Although there are many aspects of real-world social interaction that are difficult to control, in our study the same conversational partner interacted with all participants, thereby controlling factors like familiarity, sex, and personality characteristics of the conversational partner. It is difficult to assess how much the partner's behavior affected the synchronous behavior of the overall dyad; however, it is important that the partner was given the same instructions for all of the sessions as they were not told how much to talk or what to talk about. Furthermore, because our study involved female participants interacting with a female partner, we were able to control the sex composition of the dyad. All dyads were same-sex which have been shown to display higher rates of convergence on many speech related variables relative to mix-sex dyads (Bilous & Krauss, 1988). We also found no effect of the order in which the conversational data collection sessions occurred: convergence occurred in 5 of the first 10 sessions and 5 of the last 10 sessions. In the future it would be beneficial to examine multiple ways of measuring conversational synchrony across multiple interactions with different partners to see how consistent interactive behavior is. One of the main limitations of our study is our small sample size, thus we consider our findings preliminary and they need to be replicated in a larger sample in order to be fully supported. Despite our small sample size, the homogeneity of the group (all females with similar age and education) strengthens our analysis as we did not have to control for variables like sex, age, or education. However, such homogeneity may reduce the generalizability of our findings.

Our preliminary analysis of functional connectivity and conversational synchrony provides many avenues for future exploration. In the future, it would be important to see how activity of the vmPFC and rTPJ relate to other measures of conversational synchrony as there are a variety of different behaviors that have been shown to become more similar in conversation (e.g., turn length, language style matching). Furthermore, because social cognition is believed to be fundamentally different when we are interacting with others face-to-face (relative to observation or the use of verbal or visual stimuli), many researchers are working on developing new methods of studying live interaction in the fMRI scanner (e.g., Konvalinka & Roepstorff, 2012; Schillbach, Timmermans, Reddy, & Costail, 2013). As these new technologies develop, it would be important to strengthen our hypothesis about the importance and timing of the role of these brain regions using task-based functional connectivity as participants have real time ecologically valid conversation.

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Appendix A. Supplementary data

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