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The physiological basis of synchronizing conversational rhythms: the role of the ventromedial prefrontal cortex

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Abstract

Objective—During conversation, people tend to converge and become more similar across discourse characteristics, such as producing similar speaking turn lengths and even similar words. This “conversational synchrony” enhances social affiliation and rapport. Here, we investigated the role of the ventromedial prefrontal cortex (vmPFC) in conversational synchrony. We focused on the vmPFC because this region is strongly implicated in social behaviors related to synchrony, such as empathy.

Method—To examine the role of the vmPFC role in conversational synchrony, convergence of total words and words per turn were measured in the discourse of participants with bilateral vmPFC damage, healthy comparison participants (CP), and a brain-damaged comparison group with bilateral hippocampal damage (HPC) as they interacted with an unfamiliar partner.

Results—CP and HPC interactions displayed convergence as the interactants’ productions of words and words per turn became more similar across the sessions. In striking contrast, vmPFC interactions did not display convergence for either variable. A follow-up experiment revealed the same lack of convergence in the interactions of vmPFC participants with a more familiar conversational partner.

Conclusions—Our results suggest that vmPFC is a crucial part of the neurobiological system that supports the ability to synchronize conversational rhythms by dynamically adjusting behavior to the social environment.

Keywords

interpersonal coordination; speech convergence; communication accommodation; discourse; ventromedial prefrontal cortex

1. Introduction

The tendency to adapt and synchronize behavior is ubiquitous throughout nature. Indeed, synchrony in its broadest definition is observed in flocking birds, schooling fish, and parent-child interactions (de Waal, 2009). It is a driving force that compels us to be more like our conspecifics. While the dynamics that underlie this phenomenon are unknown, the by-products or consequences of synchrony are topics of considerable interest. Such consequences may include empathy, or feeling more “in tune” with another person (de Waal, 2009). In humans, synchrony¹ is readily observed in social interactions and conversation. Conversational partners tend to coordinate their speech and nonverbal behaviors (Bernieri & Rosenthal, 1991). For example, over the course of an interaction interlocutors become more similar in the lengths of speaking turns and total speaking time (Cappella & Panalp, 1981; Street, 1984), adopt each other’s accents (Giles, Coupland, & Coupland, 1991), produce similar syntactic structures (Branigan et al., 2000), use similar gestures (Holler & Wilkin, 2011), and adopt similar postures and mannerisms (Chartrand & Bargh, 1999). These forms of synchrony and coordination serve numerous purposes, including signaling active interest and involvement, enhancing rapport, and facilitating rapid processing and comprehension of language (Cappella & Panalp, 1981; Garrod & Pickering, 2009; Giles et al., 1991). Conversational synchrony is an important communicative process that facilitates development of social bonds.

Conversational synchrony seems to require participants to be highly sensitive to others’ behaviors in order to adaptively adjust and alter their own behavior. A potential neuroanatomical platform for this type of cognitive processing is the ventromedial prefrontal cortex (vmPFC), as previous research suggests that this region is involved in producing adaptive interpersonal behavior in response to changing contingencies in the social environment (Damasio, 1996; Rolls, 1996). Additionally, the vmPFC has been strongly implicated in the pro-social behaviors that synchrony and coordination are believed to influence, including empathy and understanding emotional and nonverbal social cues (Mah et al., 2004; Shamay-Tsoory et al., 2003; Stone et al., 1998). Furthermore, vmPFC involvement is found in the reward response when one’s behavior (e.g., gesture) is matched or mimicked by another person (Kuhn et al., 2010).

While there is growing evidence that vmPFC is critical in social behavior and the associated positive social benefits, few studies have examined the role of vmPFC in conversation. Given the importance of synchrony in conversation for social affiliation and empathy, and reports that vmPFC patients have impairments in sustaining normal social relationships, displaying empathy for others, and changing or appropriately adapting their behavior to changing contingencies in the environment (Beadle & Tranel, 2011; Bechara et al., 2000; Eslinger, 1998; Damasio, 1996; Rolls, 1996), we hypothesized that vmPFC damage would disrupt synchrony in conversation. To quantify conversational synchrony, we analyzed convergence of noncontent variables, specifically words and words per turn (Street, 1984).

¹Across disciplines, aspects of this phenomenon has been referred to as speech accommodation (Giles et al., 1991), interactive alignment (Garrod and Pickering, 2009), and mutual influence (Cappella & Panalp, 1981). We are using the term synchrony as it refers to a broader form of coordination in social interaction.

We predicted that synchrony and convergence would be displayed in healthy and brain-damaged comparison participant interactions, specifically, that noncontent speech behaviors between conversational partners would become more similar by the end of the conversation compared to the beginning. In contrast, we predicted that there would be less convergence of noncontent speech behaviors between conversational partners in the vmPFC interactions.

2. Methods

2.1. Participants

Participants were seven patients (4 females) with bilateral vmPFC damage (Figure 1). These participants have been well characterized neuropsychologically and neuroanatomically and all display post-morbid changes in personality, social, and interpersonal functioning (see Barrash, Tranel & Anderson, 2000). Speech and language abilities were within normal limits on standardized measures from the Multilingual Aphasia Examination (Benton, Hamsher, Rey, & Sivan, 1994) and the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983). Seven healthy comparison participants (CP) free of neurological/psychiatric conditions were matched pairwise to each vmPFC participant on sex, age, and education. To investigate whether brain injury per se might account for observed effects, a brain-damaged comparison group was included. We took advantage of another well-characterized group in our laboratory, four participants (3 females) with focal bilateral hippocampal damage (HPC) and severe declarative memory impairment. Both the HPC and vmPFC groups have similar within-group lesion and neuropsychological profiles. Also, the HPC group allows us to answer a secondary research question about the role of memory in conversational synchrony.

2.2. Conversational sample

Conversational samples were collected using the Mediated Discourse Elicitation Protocol designed to support ecologically valid interactional discourse sampling (i.e., partner contributions are not restricted or scripted) (Hengst & Duff, 2007). Briefly, this protocol allows for the collection of naturalistic conversational data where participants were told they were simply going to have a conversation, just as they would with anyone in everyday life. Although not part of the protocol, typically the partner began the session with a statement about current events or question for the participant (e.g., How was your drive?). Two females served as interactional partners for the 18 sessions; one (who interacted with 3 vmPFC and 3 CPs) was blind to participant status, both partners were blind to study hypotheses, and neither had previously interacted with any of the participants. Other than training in the protocol (e.g., sequence of discourse activities), no other training or feedback was given (e.g., what to talk about, how much to talk).

2.3. Coding interactional turns and words

All sessions were videotaped and transcribed. Coding of interactional turns and words followed previous procedures (Duff et al., 2008). Briefly, interactional turns were defined as utterances produced by one individual and could include both verbal and nonverbal resources (e.g., head nod) alone. Turn boundaries were denoted by a change in speaker. Across all interactions, 4,261 total interactional turns were coded with no significant group

differences (vmPFC, $M=210.4\pm49.9$ turns; CP, $M=233.7\pm79.2$ turns; HPC, $M=288.0\pm89.0$ turns; $F(2,17)=1.5$, $p=.25$).

Words were broadly defined and word counts included false starts (e.g., *Yes- Yesterday*), fillers (i.e., *uh*) and backchannel responses (i.e., *yeah*). Across all interactions, 42,538 total words were coded with no significant group differences (vmPFC interactions, $M=2236.4\pm536.6$ words; CP, $M=2590.1\pm822.3$ words; HPC, $M=2188.0\pm447.1$ words; $F(2,17)=.70$, $p=.51$). The vmPFC, CP, and HPC sessions were also similar in mean session length (11:46 $\pm$ 3:01, 14:02 $\pm$ 4:21, and 13:23 $\pm$ 3:50 (min:sec) respectively; $F(2,17)=.65$, $p=.53$). Finally, sessions performed by the two interactional partners were similar across all measures; mean length ($t=1.02$; $p=.32$), total words ($t=.97$; $p=.34$), and turns ($t=.28$; $p=.78$).

2.4. Noncontent speech convergence analysis

Noncontent speech convergence of words and words per turn was selected as it has been used extensively in communication research (e.g., Cappella & Panalp, 1981; Street, 1984), is independent of topic or content of the conversation, and characterizes the mutual nature of dialogue at a fundamental level. Furthermore, while many previous studies on conversational synchrony have used temporal measures, such as pause times and vocalization times, we have chosen broadly defined word counts and words per turn as measures of noncontent speech convergence as they do not rely on temporal factors that may be disrupted as a result of nonspecific brain damage. Noncontent speech convergence coding of total words and words per turn (i.e., turn duration) was adapted from Jones et al. (1999), by comparing the frequency of behaviors produced early in the conversation to the frequency of these behaviors later in the conversation by first calculating and adjusting the frequency of behaviors into segments of approximately 60 seconds, while respecting turn boundaries. Then, to determine if participants became more similar over the course of the interaction, the percent difference between the number of words (or words per turn) between participant and partner was calculated for each segment and averaged over the first quarter of the interaction (typically 2–3 segments) and compared to the percent differences of these behaviors over the last quarter of the interaction.

To assess each individual dyad's change across the interaction, a convergence score was calculated, reflecting the absolute change in the production of the target behaviors (e.g., words) relative to the beginning of the session. This was calculated for each dyad by subtracting the absolute percent difference between the productions of the participant and partner during the first quarter of the session, from the absolute difference in their productions in the last quarter of the session, divided by the absolute percent difference during the first quarter of the session. For example, if Participant A spoke 24% more words than the partner in the first quarter of the interaction, and 2% more words than the partner in the last quarter, the convergence score is $(2\%-24\%)/24\%=-0.9$. Convergence is displayed if the dyads reduce the differences in their productions across the interaction relative to the beginning, reflected by convergence scores less than 0 but greater than or equal to -1. This was the predicted outcome for CP interactions. A second example is if Participant B spoke 24% more words than the partner in the first quarter and 26% more words than the partner in the last quarter. In this case the convergence score would be $(26\%-24\%)/24\% = 0.08$.

Convergence is not displayed if productions do not become more similar (i.e., remain the same or become more different) by the end of the conversation, reflected by convergence scores of zero or greater. This was the predicted outcome for vmPFC interactions.

3. Results

3.1. Words

The interactions of healthy comparison participants (CPs) and patients with hippocampal damage (HPC) displayed convergence for the number of words produced across the interaction. The average convergence scores of the groups, as well as the vast majority of individual scores, fell within the convergence range of 0 to -1 (Figure 2a). Thus, dyads became more similar to one another during the interaction. In contrast, in vmPFC interactions, the group average convergence score, and the majority of individual scores fell in the positive range, indicating the dyads did not become more similar. An ANOVA revealed a significant group difference $F(2,17)=8.9, p=.003, \eta^2 = .54$, and planned comparisons revealed a significant difference between vmPFC and CP interactions ($p=.002$) and between vmPFC and HPC interactions ($p=.004$), and no significant difference between HPC and CP interactions ($p=.886$).

3.2. Words per turn

The interactions of healthy CPs and HPCs displayed convergence for the number of words per turn produced, as all of the individual dyads displayed convergence and fell within the convergence range of 0 to -1 (Figure 2b). In vmPFC interactions, the average convergence score, as well as the majority of the individual scores fell in the positive range, reflecting that the dyads did not become more similar to one another. An ANOVA revealed a significant group difference $F(2,17)=4.3, p=.03, \eta^2 = .36$, and planned comparisons revealed a significant difference between vmPFC and CP interactions ($p=.01$). The difference between the vmPFC and HPC interactions was not quite significant ($p=.08$), and there was no significant difference between HPC and CP interactions ($p=.58$).

3.3. Dynamics of the sessions

Focusing on the interactions of CP and vmPFC interactions, we further explored the contributions of the target participant (the healthy comparison person or the patient with brain damage) and the partner (the person recruited to serve this role in the experiment) to the session. Figure 3 shows the percentage of words produced by the target participants and partners in the CP and vmPFC sessions across time. In the CP sessions, at the beginning of the interaction, the target participants produced on average 74% of the words, but by the end produced on average 53% words. The partners produced on average 26% of the words in the beginning and 47% of the words at the end. This is a striking display of convergence, as by the end of the session, not only did the target participants and partners become more similar, but they also each produced roughly 50% of the words – a conversation with essentially equal contributions. In contrast, the vmPFC participants produced 67% of the words in the beginning of the session, and continued to produce 68% of the words by the end of the session, reflecting interactions that are dominated by the vmPFC participants throughout. Likewise, the partners also exhibited virtually no change across sessions, producing on

average 33% of the words at the beginning and 32% at the end. A 2 (group) $\times$ 2 (interactional partner)² $\times$ 2 (session epoch) repeated measures ANOVA was performed. A significant interaction between group and session epoch was found $F(1,10)=18.09$, $p=.002$, $\eta^2 = .64$, as word productions in the vmPFC sessions did not change over time, while they did change in the CP sessions. Note that while no instructions were given to either member of the dyads (target participant or partner) regarding how much to speak or what to talk about, in many cases, perhaps due to the nature of being in a laboratory setting, in the beginning of the interaction the target participant tended to speak more than the partner across groups. Critically, for testing our main hypothesis, the most important part of the convergence analysis is the change in behaviors across the interaction, and it is this change that differentiates the groups—vmPFC interactions failed to “converge.”

Interestingly, the lack of convergence is not only represented in the behavior of the vmPFC participant: the percentage of words produced by the partner in the vmPFC sessions also does not change over time. Recall that these same conversational partners conducted the CP sessions (and HPC sessions) and successfully displayed convergence. Thus, convergence is impaired in sessions where one partner has vmPFC damage, and lack of convergence is evident in the behaviors of the vmPFC patient as well as the conversational partner.

3.4. Follow-up Experiment

To investigate further the effect of the partner of the lack of convergence in vmPFC sessions, we collected data from 5 of 7 vmPFC participants interacting with two additional partners. Each vmPFC participant interacted with a different new unfamiliar female partner between 20–30 years old and with a familiar female partner in her late 50s (a research assistant who has worked closely with these participants for 10–25 years). As in the primary study, interactants were instructed to simply have a conversation; no training or further instructions were given. All unfamiliar partners were blind to participant status, and both unfamiliar and familiar partners were blind to study hypotheses. Similar to the primary study, overall, vmPFC interactions with both the unfamiliar and familiar partner did not display convergence for words or words per turn as illustrated by their average and individual scores (Figure 2a, b). Analyses of the dynamics of these sessions were similar to those of the primary study. In both sessions there was little change in the productions of both the vmPFC participant and the partner. In the unfamiliar partner interaction, the vmPFC participants produced 69% of the words in the beginning, and 67% in the end, and in the familiar partner sessions, the vmPFC participants produced 61% of the words in the beginning, and 64% in the end of the interaction. This suggests that across multiple partners, convergence is impaired in both the vmPFC participant and the partner in the vmPFC sessions. This further supports the notion that the nature of the vmPFC interactions negatively impacts the partners' ability to converge. Examples of individual data from all sessions are in Tables 1 and 2.

²Interactional partner was included as a factor in this analysis to determine whether there were differences between sessions for the two different interactional partners. Neither the main effect of partner, $F(1,10)=.00$, $p=.99$ nor the interaction between partner and session epoch, $F(1,10)=.05$, $p=.82$ were significant.

4. Discussion

The critical finding here was that interactions between patients with vmPFC damage and a partner, irrespective of the level of familiarity, did not display conversational synchrony as measured by convergence of words or words per turn. By contrast, interactions with healthy CP and HPC participants did display conversational synchrony.

These findings are important in several key regards. First, these findings contribute to theories of the neurobiology of complex communication. It has been proposed that the vmPFC is involved in the production of socially advantageous behaviors in conversation and for pragmatics in conversation (Body, 2007; Schumann, 1999). Yet research on the neural substrates of interactive alignment, or how conversational partners align their linguistic representations in order to facilitate understanding, has not considered a role for the vmPFC (Meneti et al., 2012). Our results provide compelling evidence that the vmPFC contributes to a fundamental physiological ability to align or synchronize conversational rhythms (Bernieri & Rosenthal, 1991). Our results provide support for the hypothesis that through similar mechanisms used to produce adaptive responses to other socially relevant stimuli in the environment, the vmPFC contributes to *how* mutual conversation is produced by adaptively altering verbal output, on the fly, to match that of a conversational partner.

Importantly, conversational synchrony is a collaborative phenomenon as the behaviors of both conversational partners can change to become more similar to each other. Given the role of the vmPFC in understanding the thoughts and feelings of others, a disruption in “mentalizing” (Amodio & Frith, 2006) could also negatively affect their conversational partners’ ability to converge or become more similar to the patients. We have evidence that the observed disruptions in the conversational synchrony of patients with vmPFC damage is a combination of the patients’ failure to “converge” and the ongoing, dynamical influence this has on the behavior of the partners. The same communication partners who successfully displayed convergence with healthy partners (and the HPC sessions) failed to do so in the vmPFC sessions. We speculate that this is in part due to the cooperative, reciprocal nature of conversation: if one person is dominating the floor, it is more difficult for the partner to increase their talk time. It seems that vmPFC dysfunction affects not only the ability of the vmPFC patient to exhibit conversational synchrony, but also the dynamics of the session in such a way as to prevent convergence by the conversational partner. Nonetheless, while the dynamics that led to the lack of convergence may be clarified in further studies, the finding that interactions with vmPFC patients do not display conversational synchrony for words or turn duration supports the idea that the vmPFC is a critical substrate for synchrony in certain aspects of conversation. Moreover, the fact that the same outcome obtained across different communication partners supports the notion that the lack of convergence is a common feature in the interactions of vmPFC patients, irrespective of the partner.

Second, these findings enhance our understanding of the mechanisms of empathy, as conversational synchrony is believed to be important for the development of social bonds (e.g., Giles et al., 1991) and empathy (de Waal, 2009). While we did not measure empathy directly, it is clear that an interaction lacking equal opportunities for both people to contribute can impact perceptions of empathetic concern. Likewise, previous research has

shown that conversational synchrony can impact social coordination (Fusaroli et al., 2012) and the development of rapport and feelings of a successful mutually fulfilling interaction (Giles et al., 1991). Although we did not ask participants in the current study to rate the perceived quality of the interaction, our results suggest that vmPFC patients have a tendency to dominate conversations. In fact, one of our most striking anecdotal observations of our conversations with vmPFC patients over the years is that we frequently felt as though the conversations lacked a sense of balance and harmony; in the current experiment, we found empirical support for this observation. Conversations between two individuals involve mutual dialogue, and a lack of balanced opportunities for both persons to contribute can encumber the development of rapport and result in conversational partners not feeling “in tune” with one another. Disrupted conversational synchrony may account for or be related to the poor quality of social interactions and interpersonal relationships in patients with vmPFC damage, commonly reported by family members but hard to capture in the laboratory (e.g., Gupta et al., 2012). Finally, since the vmPFC is particularly susceptible to damage in traumatic brain injury, and often times TBI patients present with similar neuropsychological profiles and reported impairments in social functioning as participants with focal vmPFC damage, we find this work encouraging for the clinical implications it has for populations such as TBI.

The finding that hippocampal amnesic patients did not differ from healthy participants in their ability to display convergence suggests specificity of vmPFC in conversational synchrony as opposed to a more general consequence of brain injury. Moreover, that amnesia does not impair this ability is interesting in its own right. While hippocampal amnesia disrupts a number of linguistic and interactional discourse functions in conversation (see Duff & Brown-Schmidt, 2012 for review), our results suggest that convergence and accommodation are independent of hippocampal declarative memory. Instead, these processes may depend on intact implicit memory systems known to support priming and other aspects of conversational alignment (Ferriera et al., 2008).

Synchrony is frequent in interactions and enhances social bonds. Our results suggest that the vmPFC is an important neural substrate for the measures of conversational synchrony used here: convergence of words and words per turn. We predict that the role of vmPFC would extend to other aspects of behavioral synchrony including body movements, gestures, gaze, as well as other physiological forms of synchrony, although this is a matter for future work. Further investigation of synchrony and its neural underpinnings promises to elucidate our understanding of empathy, communication, and other aspects of complex human behavior.

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Figure 1.

Lesion overlap map of six of seven vmPFC participants. The vmPFC was defined as encompassing the medial orbital sector and the lower medial sector of the prefrontal lobes (Brodmann areas medial 11, 25, 12, ventromedial 10, and anteroventral 32). Displayed here are (a) frontal, (b) ventral, (c) right mesial, and (d) left mesial surfaces of the brain. One patient was not included in this map, because the lesion is difficult to transfer reliably into common brain space due to uncertainties about the lesion boundary, however this patient has a bilateral vmPFC lesion similar to the other patients, that includes the mesial orbital cortex and lower mesial prefrontal cortex posteriorly, along with the white matter subjacent to these regions.

Figure 2.

a,b. Convergence scores for the primary study for words (Fig. 2a) and words per turn (Fig. 2b) for comparison participants (CP), hippocampal participants (HPC) and ventromedial prefrontal cortex participants (vmPFC) interactions with average and individual data plotted. The highlighted area reflects scores displaying convergence. CP and HPC interactions display convergence as their scores are between 0 and -1, reflecting that the partners' productions have become more similar by the end of the interaction relative to the beginning. In striking contrast, the vmPFC interactions do not display convergence as the majority of the scores are in the positive range, reflecting that the partners' productions became less similar to one another over the course of the interaction. Data from the follow-up study with 5 of 7 vmPFC participants each interacting with a different new unfamiliar partner and the same familiar partner are also shown. Note: The individual datapoints in the vmPFC sessions where there was successful convergence are not the same patients across sessions.

Figure 3.

The percentage of words produced by both the participant and partner in the comparison (CP) and ventromedial prefrontal cortex (vmPFC) sessions across time. Error bars represent SEM.

Table 1

Examples of individual data showing the average number of words produced during the first quarter and the last quarter of the interaction.

		First quarter (average words)	Last quarter (average words)
Primary Study	CP participant	128.6	90.6
	Partner	36.0	84.6
	vmPFC participant	137.3	185.0
	Partner	48.0	26.0
Follow-up	vmPFC participant	138.0	308.8
	Unfamiliar partner	74.3	39.8
	vmPFC participant	154.0	170.3
	Familiar partner	54.5	62.3

Note: CP=comparison participant; vmPFC= ventromedial prefrontal cortex participant. Also displayed are the data from the follow-up study for the same vmPFC participant interacting with a new unfamiliar partner and familiar partner.

Table 2

Examples of individual data showing the average number of words per turn produced during the first quarter and the last quarter of the interaction.

		First quarter (average words/turn)	Last quarter (average words/turn)
Primary Study	CP participant	41.0	11.3
	Partner	2.6	9.4
	vmPFC participant	13.8	86.2
	Partner	3.6	2.3
Follow-up	vmPFC participant	50.8	98.1
	Unfamiliar partner	3.8	1.3
	vmPFC participant	47.4	232.5
	Familiar partner	4.9	46.2

Note: CP=comparison participant; vmPFC= ventromedial prefrontal cortex participant. Also displayed are the data from the follow-up study for the same vmPFC participant interacting with a new unfamiliar partner and familiar partner.