Chapter 4

Prefrontal Cortex: Role in Language Communication during Social Interaction

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Abstract

One important question that remains open for the relationship between the brain and social behavior is whether and how prefrontal mechanisms responsible for social cognitive processes take place in language communication. Conventional studies have highlighted the role of inferior frontal gyrus (IFG) in processing context-independent linguistic information in speech and discourse. However, it is unclear how the medial prefrontal cortex (mPFC), the lateral prefrontal cortex (lPFC), and other structures (such as medial superior frontal gyrus, premotor cortex, anterior cingulate cortex, etc.) are involved when socially relevant language is encountered in real-life scenarios. Emerging neuroimaging and patient studies have suggested the association of prefrontal regions with individual differences and impairments in the comprehension of speech act, nonliteral language, or construction-based pragmatic information. By summarizing and synthesizing the most recent functional magnetic resonance imaging (fMRI) studies, this chapter aims to show how neurocognitive components underlying the social function of prefrontal cortex support pragmatic language processing, such as weighing relevant social signals, resolving ambiguities, and identifying hidden speaker meanings. The conclusion lends impact on an emerging interest in ***neuropragmatics*** and points out a promising line of research to address the mediating role of prefrontal cortex in the relation of language and social cognition.

Keywords: neuroimaging, speech act, nonliteral meaning, pragmatics, social interaction

1. Introduction: indirect language and social inferential networks

Language is uniquely human in that the communication via language is inherently social [1]. Unlike other cognitive systems such as visual perception which does not necessarily involve the input from social interaction, the human acquisition of language-processing abilities heavily rely on the social input. One of the main functions of language is to establish, maintain, and modify social relations. The meanings that are conveyed by language are situated in social settings and are hence highly negotiable. Newly emergent research in cognitive neuroscience of language argues that the meaning at different linguistic levels depends on social interactions and ongoing representation of body actions [2]. This chapter therefore elucidates the neural representations underlying social language processing, summarizing the representative studies that showed the involvement of prefrontal regions during processing language that conveys social information or supported by social interaction. We highlight that multiple neurocognitive components underlying social functions in the prefrontal cortex have successfully guided humans to understand language in social contexts. We will extend our perspectives into (1) indirect language and social inferential networks, (2) recognizing speech/communicative acts and action-related networks, the relation between prefrontal deficits, pragmatic impairments, and the role of theory of mind (ToM) and executive functions; (3) neural correlates of reading emotion-laden literary; (4) transmission and learning of language in social contexts; and (5) cognitive empathy and pragmatic language processing.

To detect that a conversational turn is intended to be ironic or sincere, the listener must go beyond the literal meaning. The medial prefrontal cortex (mPFC), together with the precuneus and bilateral temporal parietal junction (TPJ), forms the neuronal network for mentalizing that is correlated with the speaker meaning on the overhearers (e.g., [3–5]). These regions were more active when listeners heard the ironic utterances (*Tonight we gave a superb performance* said by an opera singer after a disastrous performance; [6]), and sentences with ambiguous references (*When Beyonce met Madonna she had just had a little accident at the hairdressers*) as compared with the literal or unambiguous control sentences. Some irony comprehension tasks also found the medial prefrontal cortex (mPFC) and middle temporal gyrus (MTG)/superior temporal sulcus (STS) [7]. The irony comprehension also involved areas related with the high executive demands and integrative processes, including the inferior frontal gyrus (IFG), MTG, and dorsolateral prefrontal cortex. Recognition of communication intention during language comprehension, in particular, the comprehension of a speech act, recruits extended neural networks. Uchiyama and colleagues found prominent activation in the IFG, MTG, and mPFC during recognizing ironic meaning [8]. The authors interpreted activation in the mPFC as being related with mentalizing activity, and activation in the IFG and MTG being related with activity in the semantic-executive system engaged in the semantic retrieval, selection, and evaluation during sentence comprehension. Harada et al. examined the neural correlates using the task where the participants judged whether the protagonist in a story uttered a speech act with the intention to deceive, or whether their behavior was morally acceptable [9]. The deceit recognition task activated the bilateral TPJ, inferior parietal lobule (IPL), the right MTG and dorsal lateral PFC (dlPFC), with the dlPFC activation related with the executive demands set by the task. Both tasks activated the IFG and the right mPFC, suggesting the mPFC may more universally function as a social inference region.

While the irony is used as a prosocial communicative tool that mitigates the face-threatening of the speaker, the deceit violates the social norm that requires the speaker to make a truthful statement. However, the understanding of both speech acts involves a contrast between what a speaker affirms and his private knowledge and requires the derivation of the shared knowledge between the speaker and the listener [10]. When the speaker produces the irony, they expect the listener to detect whereas the speaker does not expect the listener to recognize the deceit. One study explored the neural activations underlying the irony and deceitful statements [11]. Healthy individuals read statements used in sincere, deceitful, and ironic way (e.g., It's a beautiful day.). In both deceitful and ironic statements, the speaker implies the opposite of what he says [12, 13]. Compared with the since voice, both deceitful and ironic voices increased activations in the left fronto-temporal network, including the left IFG, dlPFC, and middle frontal gyrus (MFG). The IFG suggests that a demanded inferential process of the correct intended meaning from the (wrong) literal meaning of the utterance. The dlPFC suggests the involvement of executive functions to combine the inferences necessary to understand the speaker's intention to deceive with the comprehension that social norms are violated. The ironic statements uniquely activated the left MFG as compared with the deceitful statements. These findings highlight the role of prefrontal areas underlying both executive functions and social inference processes in the interpretation of pragmatic meanings from the statement.

The ability to detect the literal meaning maybe disrupted in schizophrenia patients who showed difficulties in successfully decoding meaning of ironic conversational turns [14] and in perspective taking and second-order theory of mind processes that the irony comprehension heavily relies on [14, 15]. Lesion and functional magnetic resonance imaging (fMRI) evidence has found the involvement of medial prefrontal cortex in theory of mind processing [16], and the involvement of right lateral temporal lobe [17] or the left MTG/superior temporal gyrus (STG) or the left lateral prefrontal cortex (lPFC) [18] in detecting nonliteral meanings. One study demonstrated that, as compared with literal statements, reading ironic statements ending the text vignettes activated a bilateral network including the left medial prefrontal and left inferior parietal gyri [18]. The increased activation in the mPFC suggests the involvement of second-order "theory of mind" processing in the ironic and sarcastic stimuli. The increased activation in the bilateral middle temporal gyrus in reading ironic statements were negatively associated with the reader's schizophrenic trait score (measured by schizotypal personality questionnaire, SPQ), suggesting that the more activated the bilateral MTG, the lower SPQ score when the participant read the ironic statement. These findings suggest that individuals with schizotypical personality traits are associated with a dysfunctional lateral temporal language rather than a prefrontal theory of mind network; moreover, the processing of ironic language maybe interrupted by neural mechanisms underlying the functional impairment of schizotypical personality [19]. A positive correlation was found between the activation in the left IFG when participants read irony and the SPQ possibly suggesting an involvement of additional semantic integration processes when the nonliteral sentence was encountered.

Indirect response is a "face-saving" strategy and serves as a tool for manipulating the addressee by a socially navigating individual. One study scanned the participants' brain when they listened to a reply from a job candidate that was either addressed to them (when they imagined themselves as the addressee) or to the interviewer in a job interview setting (when they overheard the conversations from the candidate and the interviewer [20]). They observed that the indirect reply, which functioned as a politeness strategy to mitigate the potential verbal threatening on the speaker's face (e.g., *I am planning to take a language course this summer*.

as indirect response to: *Are you fluent in any foreign languages*? vs. direct response to *What are your plans after graduation*?), activated mPFC, bilateral IFG, bilateral TPJ, and bilateral MTG in both conversation settings. The ventral salience network (dorsal portion of insula and anterior cingulate cortex (ACC)) was additionally involved in certain social scenarios when the participant was addressed directly. These findings suggest that the face-saving indirect languages engage perspective-taking and discourse mechanisms associated with the increased inferential complexity which may be irrelevant to whether the speaker was the first person or third person involved in the comprehension. Moreover, affective processing mechanism which determines whether the participant is the direct recipient of the address, with the regions encoding emotional salience involved when the listener's evaluative process is stronger as the direct addressee toward the indirect reply. These findings suggest that the social inference and selection of the appropriate meaning may serve as crucial mechanisms that draw upon medial prefrontal cortex to resolve any types of unspecified or implicit meanings which are contextualized, including the derivation of the pragmatic implicatures in nonliteral statements.

2. Recognizing speech acts and action-related networks

Language is a powerful tool to communicate the speaker's intended action. The neural correlates of speech were examined in a study in which the participants were presented with videos with the same critical utterances [21] embedded in different communicative scenarios (to name or to request the possession of the objects from the conversational partners). Speech (or communicative) acts are various in terms of one's possession of action-related and socio-interactive knowledge, which are considered to be linked with the action perception and prediction in the fronto-central sensorimotor cortex [22], the human homolog of the mirroring system across premotor inferior frontal and anterior inferior parietal cortex [23], and the mentalizing networks [24] over mPFC, ACC, and TPJ. The speech act of naming or requesting something does not differ according to the linguistic utterance used to perform the action or the physical setting during the communicative event (e.g., object and the communicative partners), but in the expectation of the action sequences in which the speech act is embedded (e.g., to point to the target to be named or to fetch the object to fulfill the request) and the intentions and assumptions of communicating partners (e.g., the speaker's desire to obtain the object during request). The request activated the bilateral premotor, the left IFG, and temporo-parietal areas that support the prediction of the subsequent actions following speech and representation of social interactive knowledge. However, the naming activated the left angular gyrus that establishes the referential relationship between a lexical item and the referred targets. A similar study focusing on the indirect request, such as *it is cold in here* used to request to close the window, as compared with the same expression for informing others of the temperature. The visual context that accompanied the utterances differed between the informing (images of a desert landscape) and the requesting (images of a window). Stronger activation in the indirect requests was observed in the fronto-central action system as well as the parietal areas related with the mirror neuron intention understanding; and in the mPFC, TPJ for theory of mind (ToM) processing [24].

Another fMRI study focused on the role of modality-preferential sensorimotor areas in processing meaning of abstract emotion words, such as "love," and mental words, such as "thought" [25]. While the prefrontal cortex (e.g., the dorsal lateral and prefrontal areas) served to activate the multimodal meanings regardless of word types, the sensorimotor regions (e.g., premotor areas, [26]; left posterior IFG and MFG, [27]; rostral part of ACC, [28]) were selectively engaged more in the abstract words. Participants read silently abstract emotional and mental nouns along with concrete action-related words. The regional-of-interest analysis showed that the face motor areas in the left precentral somatotopy was involved when the mental nouns and the face-related action words were encountered, while both the precentral hand and face motor areas were recruited when participants read abstract emotion words [29]. The sensorimotor systems in semantic processing are not restricted to the concrete action words but should be extended to some mental concepts. The causal role of prefrontal regions in the abstract emotion and interpersonal mental words were also demonstrated. For example, patients with a focal lesion of the left supplementary motor area (SMA) showed selective deficit in processing abstract emotional nouns. The interpersonal words (such as "convince," [30]) were found to activate the medial prefrontal, post-cingulate cortex (PCC), and orbitofrontal cortex, areas identified to be involved in mentalizing and social cognition processes. The prefrontal region, especially those which are necessary for integration of social knowledge and one's action, participated in the understanding of communicative (speech) acts.

3. Prefrontal deficit, impairment in pragmatic ability, theory of mind, and executive function

Injuries in the prefrontal and other regions are shown to causally involve in the impaired communicative-pragmatic ability. Traumatic brain injuries are typically characterized by the damage to the frontal lobes, resulting in deficits in executive functions, and the ability to manage goal-directed behavior. ToM difficulties were able to predict poor performance in speech production task. Moreover, the impact of ToM on one's communicative performance was more pronounced when the task involved stronger inhibition, for example, when participants were asked to initially think about a specific event from their own perspective, inhibit that perspective and switch to someone else's perspective. Individuals with the traumatic brain injury (TBI) suffer from a general difficulty in managing social communication in everyday life, for example, they display poor ability to negotiate efficient request [31] or at giving right amount of information to the interlocutor [32], conversational problems including turn taking [33], and narrative disorders [34]. In a study on the communicative ability in TBI individuals [35], 30 patients with traumatic brain injury and 30 healthy individuals were tested on executive function, theory of mind, and communicative-pragmatic functions using the Assessment Battery of Communication (ABaCo). Among all TBI patients, 25 suffered from focal damage in the frontal regions (among whom 15 were lesioned in the right frontal, 6 in the left frontal, and 6 in bilateral frontal or frontal-diffuse areas). The TBP participants were poor in the comprehension and production tasks in the ABaCo, on both linguistic and extralinguistic measures, as well as in the EF (higher-level executive control tasks including the working memory, planning, and cognitive flexibility) and ToM tasks (including the first- and second-order theory of mind, or mentalizing the other person's mind or the another's knowledge toward others), the latter of which predict individual's performance in the communicative-pragmatic tasks.

4. Neural correlates of reading emotion-laden literary

Reading literaries (such as poems and novels) bring various affective feelings, such as sadness, feelings of suspense, and beauty. The literary reading is a constructive process, linking to perspective taking and relational inferences associated with the extended language network [36], the ToM network [37], and regions associated with the mood empathy [38] and esthetic positive feelings [39]. The emotional connotation of single words recruits attention and can induce engagement for readers of texts and seems to be the supported by the activities of prefrontal affective networks. Ferstl et al. [40] revealed the auditory presentation of the emotion-laden text passages activated ventral mPFC (vmPFC), the left amygdale, and the pons. Wallentin et al. further showed the neural correlates of intensity ratings of each line of the text in the bilateral temporal, IFG, and premotor regions, and the right amygdala [41]. An fMRI study by [42] presented 120 short passages from the Harry Potter book series. Three levels of emotional ratings were used as the regressor for the parametric analysis: the rating of single words, the rating of the relation between words (e.g., the contrast in the emotional valence between words), and the rating of a whole passage. The contrast between the literary reading and fixation engendered activations in the dorsal lateral PFC, TPJ, anterior temporal lobe (aTL), precuneus, and amygdala which are associated with the ToM or affective empathy processing [43] and aTL and vmPFC associated with the multimodal integration and emotional conceptualization [44]. They also demonstrated that the arousal ratings on the lexical items and inter-lexical items were correlated with the activity in areas associated with emotional salience, emotional conceptualization, situation model building, multimodal semantic integration and theory of mind. For example, the more positive valence was found in the left dlPFC, left premotor, bilateral aTL, left TPJ, left PCC, precuneus. Lexical valance span varied in the left amygdala which was demonstrated to involve salience detection and the effects of arousal span were significant in the anterior insula, extended from IFG, which was demonstrated as integration of autonomic processes with emotional and motivational functions. However, no effects of ratings on passages were demonstrated in emotion-associated regions, but in ToM or affective empathy processing and multimodal semantic integration (IFG, dlPFC, aTL, TPJ, precuneus, dorsal ACC, vmPFC). This finding was different from the observation in Altmann et al. [45]. Stories with negative valence were found to activate stronger connectivity between the mPFC and left amygdala and bilateral insula, regions involving affective empathy and ToM processing. Moreover, the mPFC was more activated when the reader showed more positive judgments toward the negative stories. Whether the emotion potential of short texts can be uniquely predicted by lexical and inter-lexical affective variables or also by passage-wise rating is worth further investigation.

A related question is how one's language experience (e.g., familiarity, age of acquiring the language) affects the brain responses (especially the prefrontal involvement) underlying the reading of emotion-laden literature. Reading fictions involves language-related processes including constructive content imagination and simulation [46], perspective taking and relational inferences [47]. These processes were represented by the extended language network associated with discourse comprehension, the neural mechanisms underlying high-level/multimodal semantic integration [44, 48], and theory of mind network, generally including vmPFC, dmPFC, IFG, aTL, TPJ, PCC, precuneus, and left amygdala. The effects of emotionality were demonstrated to predict the left amygdala, vmPFC, and the pons when listening to emotion-laden text passages [40]. Ref. [49] showed that the happy passage activated left precentral gyrus (the head/face area on the somatotopy) and bilateral amygdala when the literature was presented in reader's first language (L1 reading, German) only; while regardless of the language status, the emotion-laden literature activated emotion-related amygdala and lateral prefrontal, anterior temporal, and temporo-parietal regions associated with the discourse comprehension, high-level semantic integration, and ToM processing. Moreover, the multivariate pattern analysis approach revealed better accuracy of differential patterns of brain activity in predicting different emotional contents in L1 than second language (L2), with the sensitivity attenuated in the L2 relative to the L1. These patterns showed the neural activations that support provide stronger and more differentiated emotional experience in reading our native than the second language texts.

5. Transmitting and learning language in social contexts

How are messages propagated? What are the underlying neural mechanisms? One key aspect regarding how our language is grounded into the social interaction is the synchronized linguistic behavior between communicative partners. The tendency to become more similar in the use of nonverbal cues (e.g., [50]), linguistic structures (e.g., [51]), and neural activity associated with producing and decoding narratives (e.g., [52, 53]). Are the mechanisms of verbal synchrony or linguistic style matching between communicators applied to the relationship between the use of social language by one communicator and that by the listener who subsequently retransmit the message? One fMRI study addressed the neural mechanisms underlying the processing and retransmission of social language in the context of word-of-mouth sharing [54]. The brain systems that are engaged in considering the mental states of others are particularly engaged by social features of language (e.g., words associated with social interaction, which referred to individuals who maybe participate in a social interaction, such as "friend", or those used to describe these interactive processes, such as "exchange"), and the activity within the brain's mentalizing system during exposure to ideas predicts the subsequent extent to which social language is employed in describing the ideas to others. In particular, the brain mentalizing system included the bilateral TPJ, dorsomedial prefrontal cortex (dmPFC) as well as the precuneus and PCC [55]. Previous literature has examined the mechanisms of successful communication in pairs [52, 53] and how simulation of other's mental states can facilitate effective idea retransmission [56, 57]. They showed that the use of more social words to introduce ideas was associated with increased neural activation in the dmPFC, bilateral TPJ, and temporal pole in the participants, the networks that were typically responsible for mentalizing. Moreover, the higher levels of activity in left TPJ and dmPFC during idea exposure were positively associated with greater usage of words from social categories after the experiment. Here, the dmPFC is considered as functions associated with considering other's attributes and motivations [58, 59], and reflected the pursuance of specific motivational goal for the speaker (e.g., to look good by communicating good ideas in a compelling way to others). These findings consolidated the idea that the social cues in language (here the lexical item related with social interaction) can activate the medial prefrontal and other systems implicated in understanding the mental states of others (who introduced the ideas toward a new object) and successfully retransmission of ideas.

Social communication is fundamental to human daily activity [60–62] and is contributed considerably by nonlinguistic social cues [63]. A growing number of literatures have suggested that the social inference networks, including understanding other's mental states and monitor other's feelings, maybe implicated during communicative tasks. One may recognize other's intention by two ways. One may recruit the motor simulation process which involves the premotor cortex (PMC) and the anterior intraparietal sulcus (aIPS), especially in tasks which require the understanding of the intention conveyed by body motion [64]. The other is related with inferential processes based on "theory of mind" [65] or mentalizing, which has been typically represented by regions non-overlapping with the motor system, including the mPFC, the TPJ as well as the posterior superior temporal sulcus (pSTS) [66]. These regions are mainly involved when intentions were embedded in stories or cartoons in which the goals or beliefs of the characters are not explicitly encoded by communicative cues [67], or when individuals were instructed to identify the intentions of actors they observe [68].

Nonverbal communicative cues (e.g., gaze, voice) are essential social signals in language communication. To understand how the mentalizing and mirroring system contribute to the recognition of intention via nonverbal communicative cues, an fMRI study focused on communicative (e.g., looking at a person) and private intentions (e.g., looking at an object) as well as other-directed and self-directed intentions (whether facing the camera and therefore the participants [69]). Previous studies on cartoons have demonstrated that mentalizing areas was involved when cartoons contained more social interactions, the characters showed less private intentions and more social prospective intentions (e.g., preparing future social interactions, which is considered as more "communicative intentions") [67, 69]. The right TPJ was activated regardless of the intention type, the mPFC was selectively activated in the social prospective and communicative intentions. The dmPFC was considered uniquely involved in the decoding of intention during movement observation. The dmPFC has been associated with the social gaze shift, with increased activity when participant's gaze shift is directed at another person [70] or when they follow the gaze of another person to engage in joint attention [71], suggesting a role of medial prefrontal cortex in the engagement of social communication in a second-person perspective. The participants watched videos in which the actor either faced and looked toward the camera, faced toward but looked away from the camera (at an object at his/her hand), or faced 30° away from the camera and looked toward another person outside of the camera, faced away and looked away from the camera. Observing actions performed with a communicative intent (looking toward the person) versus private intent (looking away from the camera) activated in mPFC, bilateral pSTS, and left TPJ for the mentalizing network and bilateral PMC, bilateral aIPS fo the mirroring system. The mPFC activity increased as the increasing of the individual's trait empathy. Self-directed (0° away from the camera) versus other-directed orientation (30° away from the camera) activated the visual cortex, and the enhanced activation was found in mPFC for the self-directed orientation in the communicative as compared with the private intention. Moreover, the communicative intent further strengthened the connectivity between the mPFC and the bilateral pSTS for the mentalizing system and the left PMC and bilateral aIPS for the mirroring system. These findings suggest a collaboration between the medial prefrontal cortex and other social inference networks during intention recognition in nonverbal communication.

Studies also demonstrated that the prefrontal cortex is more involved during language acquisition that occurs in a social interaction scenario. Infants must be immersed in a language in a socially interactive situation to develop speech perception [72]. Similar to the spoken language, the sign language provides rich grammatical rules and both activate the left IFG during syntactic comprehension [73]. The live communication, as compared with the pre-recorded videos, is more rewarding, more arousal, provides richer sources of information (such as responsive eye gaze), and more attention-grabbing (e.g., [72]). In a study on the neural correlates of language acquisition [74], naïve Japanese participants learned Japanese sign language through an interaction with a deaf signer or via watching videos for a comparable amount of time. The group who received a live exposure showed the modulation of BOLD signals in the left IFG between two sessions of the testing when making grammatical judgments toward a sequence of signs which was absent in the group received the video exposure. The left IFG was considered as crucial for processing syntactic and other linguistic rules in the native adult which demonstrated a clear role of exposure toward the communicative environment on acquiring new linguistic knowledge (e.g., foreign language). The group receiving DVD exposure revealed the activation in the right IFG and right supramarginal gyrus, suggesting that they developed the knowledge of sign language through incorporating multimodal information from different senses and from imitation learning [75].

Many forms of social interaction are not carrying explicit mentalizing demands. These implicit mentalizing processes include tracking mental state content [76, 77] and monitoring other's communicative intent [70] which are more engaged when processing communicative cues from a real-time social partner than those from a pre-recorded video. A similar experiment invited the participants to listen to short vignettes and were persuaded to believe half to be pre-recorded and the other half to be presented over a real-time audio-feed by a live social partner [78]. Mentalizing regions (which were defined from an independent localizer paradigm with a typical false belief task, in particular dorsal/middle/ventral mPFC and bilateral TPJ [79]) and activations associated with social engagement [66] were observed when participants believed that the speech was live than they listened to recorded matched human speech. The right dmPFC was further correlated with the subjective rating of the liveness for the live speech versus the matched speech and with the individual's autistic traits (measured by autistic quotient [80]). The increased activity in the dmPFC was, the higher rating of liveness for the live speech versus the matched speech, and the lower score in the autistic-like traits. As the mentalizing regions were observed in fMRI studies of speech comprehension [43, 81, 82], the increased activity in the prefrontal mentalizing networks maybe attributed to the increased belief state reasoning during live interaction, or due to an ongoing representation of a social partner that underlies phenomena such as a social resonance, synchrony, and coordination. These findings suggest that the medial prefrontal cortex as a key region to indicate the ongoing mentalizing about social partners, were shaped by social context, and may be crucial for understanding the implication of social context for typical and atypical social processing, especially for neurodevelopmental disorders like autism who suffer more from social difficulties in live interaction.

The studies on language communication should be better fit into the large picture of the emergent contributions to the social brain, especially in the study of brain-to-brain coupling for learning, (re)constructing and using language through multi-participant experiments [2]. An fMRI study scanned the speaker's brain when they produced a 15-min-long real-life narrative and the listener's brain when they listened to the same narrative [83]. The brain regions specific to production and comprehension, and those that are overlapped between the two processes were examined. The left hemisphere and the bilateral temporal networks under the production of the narrative were shared with those under the comprehension system. Moreover, areas in which the neural activity was coupled between the speaker's and the listener's brains in both linguistic and extralinguistic areas during production and comprehension of the same narrative were shown. The narrative production engendered activations in social aspects of the story processing (e.g., mPFC, precuneus, dlPFC, PCC), as well as in motor speech areas (e.g., bilateral premotor cortex, bilateral insula, and basal ganglia), in the bilateral IFG associated with the construction of grammatical structures, and in bilateral STG/MTG previously linked to speech comprehension. The coupling between the speaker's and the listener's brain responses was found in precuneus and mPFC, bilateral temporal–parietal areas associated with the comprehension, and left IFG, bilateral insula, left premotor cortex associated with the production. The involvement of the medial prefrontal cortex and precuneus in a range of social functions suggests that the ability of a listener to relate to a speaker and to understand the content of a real-world narrative seems to rely on the higher-level social processing, including the reward-based learning and memory, empathy, and ToM (for mPFC), and first-person perspective taking and experience of agency (for precuneus). In particular, the inference of another's intention through verbal cues plays an essential role during exchange of information between the speaker and the listener and is integral to the success of real-world communication [84].

6. Cognitive empathy and pragmatic language processing

The last but not the least, one important goal of neurocognitive study of language processing is to reveal how the brain operates to make pragmatic inference, that is, to derive the broader meaning of a sentence according to world knowledge, discourse, and social context, and to resolve pragmatic incongruence or failure which arises from the conflict between linguistic input and the information derived from pragmatic inference and world knowledge. Studies on nonliteral language processing has revealed that the increased inferential process associated with the derivation of the nonliteral meaning from statements such as ironic remark or indirect requests may activate the regions associated with cognitive empathy (the ability to simulate others in a fictional or real world interactive setting [24, 85, 86]), in particular, in the mPFC and TPJ. Moreover, sentences with meanings incongruent with one's real-world knowledge or other types of contextual information (such as speaker identity, counterfactual context, etc.) activated the left IFG [87–91], and some general executive control networks including right IFG, IPL, medial superior frontal gyrus (mSFG) when pragmatic incongruence between linguistic representations or meanings has to be resolved (e.g., [6, 92]). Among the prefrontal executive control networks that are involved in resolving the pragmatic incongruence, the right IFG may subserve a process that inhibits the irrelevant information to ensure a representation that is congruent with the contextual information whereas the mSFG is more generally involved regardless of contextual type. For example, Nieuwland [91] reported the right IFG only responsible for the world knowledge violation in the counterfactual context (e.g., *If NASA had not developed its Apollo Project, the first country to land on moon would be *America*) but the mSFG in both counterfactual and real-world context (e.g., *Because NASA developed its Apollo Project, the first country to land on moon has been *Russia*).

In an fMRI study, Li et al. [4] demonstrated that the cognitive empathy of readers (as measured by the interpersonal reactivity index, IRI [93]) predict the neural activations when they read sentences in which the language use failed the pragmatic constraint. In a sentence with "even" which constrained an event of low expectedness, the neutral or highly likely events were embedded, creating the underspecified (e.g., *Even such a sound can be heard by Zhang, he has a sharp hearing*) and incongruent sentences (e.g., *Even such a *loud sound can be heard by Zhang, he has a sharp hearing*). They demonstrated that when the underspecified sentences were read, the activity in the ventral mPFC was associated with the reader's fantasizing ability (an individual's trait to transpose him or herself to the character of a fictional situations, e.g., novel). The observation of mPFC and its individual differences may indicate that participants may engage an action-related fantasizing or imaging process when making inferences for the underspecified scalar implicature. When the incongruent sentences were encountered, the mSFG extending to ACC was activated and bilateral IFG was correlated with their perspective taking ability (an individual's tendency to adopt the perspectives of others and see things from their point of view). The bilateral IFG was further connected with a number of prefrontal regions such as bilateral mSFG, SMA and ACC (for the left IFG) and right dlPFC and left IPL (for the right IFG) during the processing of incongruent versus congruent sentences. These conflict control networks were involved to unify information from different sources and select the appropriate representation (inhibit the inappropriate representation) for the incongruent sentences. Most importantly, these findings suggest that the cognitive empathy (including those that involve the shift of one's perspective to the fictional character and to another's perspective) supports the neurocognitive mechanisms in making pragmatic inference and in resolving pragmatic failure.

The involvement of prefrontal cortex in pragmatic processing is also supported by evidence in individual differences in autistic-like traits during language comprehension. Individuals with autism spectrum disorders demonstrated reduced neural activities in the mPFC when they inferred pragmatic meanings from metaphors or ironic remarks [94]. Using structural neuroimaging, Banissy et al. [95] demonstrated that an individual cognitive empathy was related with the gray matter volume of the prefrontal cortex. In particular, the volume of the dlPFC was positively correlated with one's fantasy scores and the volume of ACC was positively associated with one's perspective taking scores. The functional neuroimaging further demonstrated that the activation in mPFC for fiction reading relative to nonfiction reading, positively correlated with reader's fantasizing scores [96]. Neurophysiological studies (such as electroencephalograms (EEG)/event-related potentials (ERPs)) showed that the words embedded in sentences with under-informative use of scalar quantifiers (e.g., *some people have necks*) elicited an increased N400 [97], an ERP effect which are considered to be the product of the underlying sources in inferior frontal cortex, than the words informative use of some [87]. This N400 enhancement was only observed in those showing higher pragmatic abilities (measured by Autism-Spectrum Quotient Questionnaire) but not in those with lower abilities [97]. Other studies also observed that those with higher empathic ability demonstrated larger N400 response in spoken sentences which contained words mismatching the speaker identity (e.g., *I want a teddy bear* in a man's voice) or larger late positivity effect in sentences that required the resolution of ambiguous referential representations based on a social context (e.g., a respectful second-person pronoun that is used in a directly quoted utterance that was addressed by a lower-status speaker to two potential addressees one of whom was of higher status [98, 99]). These neural mechanisms associated with pragmatic processing were either absent or altered in those with lower empathic ability.

7. Conclusion

To summarize, latest emergent literatures suggests a promising trend that researchers in language cognitive neuroscience are growingly attracted to address topic relevant to the neural correlates underlying social language processing. Despite the exciting new contributions in the relationship between neural networks underlying mentalizing/ToM, social inference, executive function, action, cognitive empathy and the understanding of different forms of nonliteral language, speech act, affection-charged literary, and pragmatic forms, it is still at the very beginning to characterize the precise role of prefrontal cortex in language communication in social contexts. More works taking advantage of the latest advancements in neuroimaging, neuropsychological testing, and even neurostimulation (transcranial magnetic/direct-current stimulation) should be facilitated to enlighten this new line of research in the broad context of neuropragmatics and cognitive neuroscience of human communication.

One future perspective is to examine the functional coupling between prefrontal regions and other parts of the brain that support the social inference via linguistic cues (e.g., vocal cues [100]) and the individual differences that modulate the strength of the functional coupling. Despite growing recent evidence with behavioral measures showing that language communication is deeply grounded in sociocultural conventions [84], few neuroimaging studies have dedicated to how culturally related linguistic and speech cues (e.g., linguistic accent) can contribute to the understanding of the role of the medial prefrontal cortex in perceiving sociocultural groups [100]. Another related question is how the knowledge regarding prefrontal cortex can illuminate the neural underpinnings of the socio-communicative deficits in

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special populations such as autism and schizophrenia, with a particular interest in the various types of pragmatic and social language processing as the medium for indexing their social interactive ability. These new proposals (with some of them being currently undertaken) will undoubtedly instigate more new endeavors to address the mediating role of prefrontal cortex in the relationship between language and social cognition.

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Conflict of interest

The author declares no conflict of interest.

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