Neurostimulation in Pragmatic Language Research: A Comprehensive Review

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ABSTRACT: Pragmatic language involves the use of language in social interactions, including understanding conversational norms, interpreting non-literal language, and using language appropriately in various social contexts. In recent years, there has been a growing interest in using brain stimulation techniques to study pragmatic language in both healthy and clinical populations. This review synthesizes recent research on the application of transcranial magnetic stimulation and transcranial direct current stimulation in pragmatic language studies, highlighting the critical roles of brain regions such as the dorsolateral prefrontal cortex, the right temporo-parietal junction, and the left middle frontal gyrus. These areas are implicated in various aspects of pragmatic language, including the processing of idiomatic expressions, the comprehension of indirect speech acts, and decision-making during communication. While current research underscores the promise of these neuromodulation techniques, further studies are needed to optimize their application in both theoretical and clinical contexts.

Keywords: neuropragmatics, non-literal language, neurostimulation, transcranial magnetic stimulation, transcranial direct current stimulation

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Dilbilim Araştırmaları Dergisi,

Pragmatik Dil Araştırmalarında Beyin Uyarımı

ÖZ: Pragmatik dil, dilin sosyal etkileşim ortamlarında kullanımını, iletişimsel kuralların anlaşılmasını, imgesel, sezdirim ya da dolaylılık içeren dilin yorumlanmasını ve dilin bağlama uygun şekilde kullanımını kapsamaktadır. Son yıllarda uluslararası alanyazında pragmatik dile yönelik araştırmalarda transkraniyal manyetik uyarım ve transkraniyal doğru akım uyarımı gibi beyin uyarımı tekniklerinin kullanıldığı çalışmaların sayısı giderek artmaktadır. Bu derleme, pragmatik dil işlemleme süreçlerinde özellikle dorsolateral prefrontal korteks, sağ temporo-parietal bağlantı bölgesi ve sol orta frontal girus gibi kritik beyin bölgelerinin işlevlerini öne çıkaran güncel araştırmaları sentezlemektedir. Derlemede bu beyin bölgelerinin, imgesel dilin yorumlanması, dolaylı söz eylemlerinin anlaşılması ve iletişim sırasında karar alma gibi üst düzey dil süreçlerinde rol oynadığı ortaya konulmaktadır. Derlemenin ortaya koyduğu mevcut bulgular, nöromodülasyon tekniklerinin pragmatik dilin farklı boyutlarını aydınlatmadaki potansiyelini vurgulamakla beraber; pragmatik dil bozukluğu olan klinik gruplara yönelik beyin uyarım teknikleri ile yapılacak daha fazla araştırmaya ihtiyaç duyulduğunu da göstermektedir.

Anahtar sözcükler: nöropragmatik, imgesel dil, beyin uyarımı, transkraniyal manyetik uyarım, transkraniyal doğru akım uyarımı

1 Introduction

The past century has been marked by significant advancements in neuroimaging and the understanding of the brain, which have also profoundly influenced linguistic inquiries. Techniques such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) scans have allowed researchers to observe the brain in action and understand language processing in unprecedented detail. These developments have bridged gaps between neurological structures and linguistic functions, enhancing our understanding of language acquisition, language processing, and even language disorders. In the last three decades, the advent of non-invasive brain stimulation (NIBS) techniques, including Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (tDCS) has further revolutionized the field and provided researchers with opportunities to investigate the causal relationships between brain activity and linguistic functions, offering insights into the dynamics of language processing, recovery after brain injuries, and the potential for therapeutic interventions. NIBS can be defined as the process of modulating the activity of nerve cells using electrical, chemical, or magnetic stimuli to alter or regulate the functions of the nervous system. The most used brain stimulation techniques are TMS and tDCS. TMS which was first developed by Barker and colleagues in 1985 (Barker et al., 1985) involves stimulating the cortex by generating a magnetic field over the scalp. In neuroscience research, TMS is frequently used to create virtual lesions in the brain, temporarily suppressing the function of a specific area to determine its functional role (Pascual-Leone et al., 1999, 2000; Hallett, 2007). Thus, TMS is a non-invasive neurophysiological technique capable of stimulating the human brain and has been used in various neuroscientific studies for the past 30 years. While neuroimaging studies can only identify correlations between cognitive processes and brain activations, TMS allows to evaluate the causal relationships between brain activity and behavior, and to examine intracortical, cortico-cortical, and cortico-subcortical interactions. Similarly, tDCS involves stimulating the brain with constant, low currents delivered through electrodes placed on the scalp. By applying a steady, low-intensity current through two electrodes, which modulates neuronal activity, it is possible to either enhance (anodal stimulation) or suppress (cathodal stimulation) certain electrical activities in the targeted brain region (Nitsche et al., 2005). It is possible to explore the functional roles of specific brain regions in various cognitive and behavioral tasks using both TMS and tDCS, providing valuable insights into the neural mechanisms underlying human cognition and behavior. To date, extensive research has been conducted using both tDCS and TMS with protocols that either enhance (facilitate) or temporarily suppress (inhibit) the activity of specific brain regions to study language and brain functions. These review studies have made significant contributions to studies on language research and the rehabilitation of language disorders (Pascual-Leone et al., 1994; Nitsche & Paulus, 2000). Studies using these techniques have shown that, in addition to classic language areas like Broca's and Wernicke's areas, broader brain networks are crucial for language processing. These networks include regions such as the inferior and middle frontal gyrus (MTG), which play roles in morphosyntactic processing and executive control (Ntemou et al., 2023), the motor and premotor cortices, which are involved in action-related language tasks (Hallett, 2007; Ntemou et al., 2023), and the temporoparietal junction (TPJ), which contributes to semantic integration and thematic role assignment (Nitsche et al., 2005; Ntemou et al., 2023). Additionally, the right hemisphere (RH), particularly areas related to emotional prosody and metaphorical language, supports paralinguistic and pragmatic aspects of communication (Hartwigsen & Siebner, 2012). Furthermore, studies have highlighted the importance of connectivity between cortical and subcortical structures, such as the thalamus and basal ganglia, in modulating linguistic functions (Pascual-Leone et al., 1999; Hallett, 2007). As a result, these findings emphasize the distributed and interactive nature of language networks in the brain. Additionally, studies on pragmatic language processing using TMS and tDCS have been increasingly common in recent years, contributing to a deeper understanding of the neural structure of linguistic communication, as well as how language is represented and processed in the brain. The first groundbreaking TMS study conducted by Pascual-Leone et al. (1991) proposed that TMS-induced speech arrest could be used as a non-invasive method for evaluating language dominance. Since then, a multitude of language inquiries have been conducted using TMS over the last three decades. This surge in research has led to the publication of numerous detailed reviews. Notably, the first known review by Devlin and Watkins (2007) summarized the first 15 years of TMS research on language. It discussed how TMS has clarified the roles of various brain regions in language, demonstrated functional connectivity related to language tasks, and shown potential for enhancing recovery in aphasia patients. Overall, the review emphasized TMS as a valuable tool for advancing our understanding of language in the brain. Hartwigsen and Siebner (2012) reviewed the role of the RH in language processing, proposing that while the left hemisphere is primarily responsible for language tasks, the right also contributes, especially in processing paralinguistic features like emotional prosody and metaphorical language. The authors emphasized the complexity of language processing and suggested that both hemispheres contribute to different aspects of language comprehension and production, challenging the traditional view of strict lateralization. More recent works include a systematic review and meta-analysis by Ntemou et al. (2023), which examined TMS studies on verbs and sentences. The review found that frontal stimulation engages inferior and middle frontal areas in morphosyntax, while motor cortex stimulation influences action verb processing. Additionally, temporoparietal regions were linked to semantic access and thematic role assignment. Several reviews also focused on the role of TMS in language rehabilitation (Galletta, Rao, & Barrett, 2011; Pisano & Marangolo, 2020; Torres, Drebing, & Hamilton, 2013). tDCS has also been frequently employed in language research. Following the initial reports by Iyer et al. (2005), which demonstrated improved verbal fluency in healthy subjects using tDCS, Flöel (2008) proposed that tDCS could enhance language functions. Since then, numerous studies have utilized tDCS in language research and rehabilitation. Subsequently, reviews on the application of tDCS in language studies have also emerged. Flöel (2012) reviewed recent developments in the use of both TMS and tDCS in language research with healthy individuals. Monti et al. (2013) further examined the progress in tDCS research on language functions, suggesting that tDCS applied to language-related brain region can modulate linguistic abilities in healthy individuals and improve language performance. These reviews have significantly advanced the field, enhancing our understanding of the research and rehabilitative roles of TMS and tDCS in language investigations.

In recent years, there has been a growing interest in using TMS and tDCS to study pragmatic language skills in both healthy and clinical populations (e.g., Boux & Pulvermüller, 2023; Martin-Luengo et al., 2023; Zhao et al., 2018). Pragmatic language, which is the focus of this review, involves the use of language in social interactions, including understanding conversational norms, interpreting non-literal language, and using language appropriately in various social contexts. Unlike neuroimaging and brain lesion studies, which primarily offer correlational data, TMS and tDCS allow researchers to explore causal relationships between brain activity and linguistic functions. This is particularly valuable in the study of pragmatics, where the involvement of multiple brain regions, often beyond the classical language areas, can lead to heterogeneous findings in neuropsychological studies with brain-injured patients. By applying these neuromodulation techniques, researchers can not only identify specific brain regions involved in pragmatic language processing but also manipulate these areas to directly observe the effects on communication abilities. This offers an opportunity to overcome some of the limitations associated with traditional methods. The current review aims to compile and synthesize studies that specifically focus on the application of TMS and tDCS in pragmatic language research, providing a comprehensive framework for researchers interested in this field and encouraging further exploration and innovation in neurocognitive studies of pragmatic language. The literature review was conducted using databases such as PubMed and Google Scholar with search terms including 'pragmatics', 'speech acts', 'non-literal language', 'TMS', and 'tDCS'. The aim was to identify current and relevant studies in this field. The search results were compiled by classifying the studies on an annual basis and examining the contents specific to the topic. By integrating recent literature, the paper will discuss and summarize previous findings related to the neurological underpinnings of pragmatic language use and consider the implications of these findings for both theoretical and practical applications in language research. This review contributes to the field by focusing on pragmatic language processing—a relatively understudied area compared to syntactic and semantic aspects of language. By synthesizing recent findings on the application of TMS and tDCS in pragmatic language research, this paper provides a framework for understanding how these neuromodulation techniques illuminate the neural basis of pragmatic communication. The motivation behind this review lies in addressing the gaps in existing literature, particularly the lack of a detailed examination of pragmatic language through causal, brain stimulation methods. These insights not only expand the theoretical understanding of neuropragmatics but also have practical implications for rehabilitation strategies targeting communication deficits in clinical populations.

The review begins with an overview of the use of brain stimulation techniques in language research, providing a foundational understanding of how these methods have been applied to study various aspects of language processing. The review then transitions into a discussion of neuropragmatics (Section 3), exploring how neuroscience has contributed to the study of pragmatic language. In Section 3.1, we delve into non-literal language, examining how brain stimulation has been used to study figurative speech. Section 3.2 covers indirect speech acts, reviewing studies that investigate how these speech act processes are modulated by brain stimulation techniques. In Section 3.3, we focus on social communication, summarizing studies that explore how brain stimulation techniques influence the neural mechanisms underlying social aspects of language use. Section 3.4 addresses gesture-speech integration, reviewing how brain stimulation is used to understand the coordination between gestures and speech. Finally, the review concludes by summarizing the key findings and implications for future research in Section 4.

2 *Pragmatic Research in Neuroscience: Neuropragmatics*

Pragmatics is the branch of linguistics that deals with language use in context and thus, represents one of the most expansive domains within neurolinguistics. It involves understanding how people produce and comprehend meanings in real-life situations, considering the speaker's intentions, the relationship between speakers, and the situational context. The study of pragmatics has a long tradition in philosophy and linguistics, examining how language functions in communication beyond its structural aspects (Stemmer, 2008). The incorporation of pragmatics into the field of neurolinguistics, known as Neuropragmatics (Bara et al., 1997; Bambini et al., 2011; Levinson, 2016; Noveck, 2018), examines how aspects of communication, including discourse, conversation, and figurative language, are managed by individuals with and without brain pathologies.

Neuroscientific studies on pragmatic language often focuses on several key aspects of pragmatics. One major area of study is non-literal language processing, which includes the understanding and interpretation of metaphors (expressions that convey meanings different from their literal sense), idioms (phrases whose meanings cannot be understood from the individual words they contain), irony (a figure of speech that communicates the opposite of what is said), sarcasm (a form of irony directed at a person, with the intent to criticize), and humor (the use of language to evoke laughter or amusement). This is because, in pragmatic language, there is a distinction between the literal meaning of what is said, and what the speaker means (Jang et al., 2013). Recent linguistic models have suggested that understanding pragmatic language draws on additional neural support beyond the traditional language system (Ferstl et al., 2008) as understanding pragmatic language goes beyond the literal meaning of words; it necessitates the listener's ability to interpret the relationships between content, context, and the speaker's intent. This additional interpretative mechanism is thought to involve the capacity to mentally construct a theory of another person's mind based on a set of known variables (Frith & Frith, 2003). In this regard, pragmatic language skills have often been associated with Theory of Mind (ToM) processes that involves the ability to understand and consider others' perspectives and emotions (Fernández, 2013; Pijnacker et al., 2012).

Neuropragmatic research traditionally gained insights from studies on brain-damaged patients. Early studies that described communicative difficulties in right-hemisphere damage (RHD) (Lindell, 2006; Champagne-Lavau & Joanette, 2009; Ferré et al., 2012; Sheppard et al., 2021; Weed, 2011) patients who can still face communication challenges despite being able to produce and understand words and sentences led to the integration of pragmatic theories into neurolinguistic research Stemmer (2008). The term "apragmatism" has recently been proposed to characterize the pragmatic language disorder following right-hemisphere stroke (Minga et al., 2023). Over time, the scope expanded to include other clinical populations, such as those with aphasia, Parkinson's disease (Holtgraves & McNamara, 2010), traumatic brain injury (TBI) (Arcara et al., 2020; see Rowley et al., 2017 for review), autism (Dennis et al., 2001; Reindal et al., 2021), schizophrenia (Corcoran et al., 1995; Mitchley et al., 1998), aging (Bambini et al., 2020; Bambini et al., 2021), developmental disorders (Hage et al., 2021), and Alzheimer's disease (Rapp & Wild, 2011; Sakın, 2021)."Many other studies have also documented impairments in various tasks, including the comprehension of humor, metaphors, proverbs, and other non-literal inferences (Brownell et al., 1990; Winner et al., 1998; Shamay-Tsoory et al., 2002; Shammi and Stuss, 1999; Martin-Rodriguez and Leon-Carrion, 2010; Lundgren et al., 2006; Cardillo et al., 2018).

Pragmatic language research has extended to include not only clinical groups but also healthy individuals, utilizing neuroimaging techniques like PET and fMRI. In these studies, pragmatic abilities have been proposed to rely predominantly on the RH (McDonald, 2000; Gibson et al., 2016). For example, in a PET study, Bottini et al (1994) asked participants to make plausibility judgements about sentences that were either novel metaphors or literal true/false statements. The authors found significant right-hemispheric activation, including an increased response in the medial prefrontal cortex (mPFC), precuneus and posterior cingulate cortex (PCC), during the processing of metaphors (Mitchell, 2009). Additional research has highlighted the involvement of the TPJ, mPFC, and precuneus in processing ironic sentences as opposed to literal ones (Shibata et al., 2010; Spotorno et al., 2012). For instance, Shibata et al. (2010) found that ironic sentences elicited greater activation in the right mPFC, right precentral gyrus, and left superior temporal sulcus compared to literal sentences. These findings suggest that key regions within the ToM neural network—mPFC, TPJ, PCC, and precuneus—extend beyond the left hemisphere and collaborate with the traditional language network to derive meaning from pragmatic language.

A growing number of brain imaging experiments have challenged the notion of (RH) dominance in comprehending non-literal language suggesting a left hemisphere involvement (e.g., Rapp et al., 2004; Lee & Dapretto, 2006; Bosco et al., 2017). In a recent meta-analysis, Hauptman, Blank & Fedorenko (2023) examined the brain mechanisms involved in non-literal language interpretation. By analyzing 74 fMRI studies with 1,430 participants, the study contrasts non-literal language comprehension with literal control conditions, identifying key brain regions involved. The findings reveal that non-literal language processing engages both the language network and the ToM network, suggesting that understanding non-literal meaning involves both linguistic and social inference mechanisms, challenging the notion that it requires additional executive resources.

In conclusion, understanding and processing pragmatic language requires a complex interaction of both linguistic and social cognitive mechanisms. Research indicates that both the right and left hemispheres are involved in these processes. While the RH plays a significant role in interpreting non-literal language such as irony and metaphors, increasing evidence also points to the involvement of the left hemisphere. ToM network, crucial for understanding others' intentions and perspectives, works in conjunction with language networks to derive pragmatic meaning. These findings highlight the intertwined nature of language processing and social cognition, emphasizing the need for holistic approaches in the evaluation and/or rehabilitation of pragmatic language skills. Neurophysiological methods like Electroencephalography (EEG) and Magnetoencephalography (MEG) have been crucial in studying brain dynamics, revealing that pragmatic information is processed ultra-rapidly and in parallel with other linguistic information, such as semantics, thereby supporting parallel models of language processing (Tomasello, 2023). In recent years, brain stimulation research has also been increasingly utilized to understand pragmatic language processes.

2.1 Non-Literal Language

Pragmatic language involves the ability to understand and use language in context, which encompasses interpreting meanings that extend beyond the literal words spoken or written. This aspect of language comprehension is particularly important when dealing with non-literal language, such as idioms, metaphors, irony, and sarcasm. Non-literal language requires the listener or reader to infer the speaker's or writer's intended meaning, often relying on context, shared knowledge, and various social cues to do so. The ability to comprehend and appropriately respond to non-literal language is a crucial component of pragmatic language skills, as it demands the integration of contextual and social information to grasp the underlying meaning of the communication.

Studies involving non-literal language processing using TMS and tDCS frequently focus on idiom comprehension (Fogliata et al., 2007; Rizzo et al., 2007; Hauser et al., 2016; Kurada et al., 2021). Because idioms are among the most prevalent forms of non-literal language in daily communication. The comprehension of idioms can be challenging because the idiomatic meaning often cannot be directly inferred from the meanings of the constituent words. When individuals process an idiom, such as "kick the bucket," two types of meanings are activated simultaneously: the literal meanings of the individual words or their combination, and the idiomatic meaning, which is understood within the context of the phrase (Cacciari and Glucksberg, 1995). This dual activation of meaning underscores the complexity of idiom comprehension and highlights the cognitive processes involved in discerning figurative language.

The first study utilizing TMS to investigate the neural correlates of idiom comprehension was conducted by Oliveri et al. (2004). This pioneering research demonstrated the involvement of the left temporal lobe in the process of understanding idioms, suggesting a significant role for this brain region in figurative language comprehension. Subsequent TMS studies have provided further evidence that stimulating prefrontal regions, particularly the dorsolateral prefrontal cortex (DLPFC), can significantly impair the comprehension of idiomatic expressions. For instance, Fogliata et al. (2007) reported that in a sentence-to-picture matching task, the comprehension of idioms was disrupted when repetitive TMS[1] (rTMS) was applied to the left DLPFC, indicating the critical role of this area in idiom processing. Further supporting these findings, Rizzo et al. (2007) found that applying rTMS to both the left and right DLPFC hindered idiom comprehension, suggesting that both hemispheres may be involved in processing idiomatic expressions, depending on the specific characteristics of the idiom. Hauser et al. (2016) extended this line of research by demonstrating that rTMS targeting the left ventrolateral prefrontal cortex (VLPFC) specifically affected the processing of less familiar idioms. This study highlights the differential involvement of brain regions based on the familiarity of idioms, suggesting that the neural mechanisms underlying idiom comprehension may vary depending on how well-known or frequently used the idiom is. A recent study by Kurada et al. (2021) further explored the role of the DLPFC in idiom comprehension by examining how idiom transparency affects brain activity. Using rTMS on the DLPFC, the study involved participants performing a semantic decision task with both opaque and transparent idioms, as

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[1] Repetitive Transcranial Magnetic Stimulation is a non-invasive neuromodulation technique that delivers repetitive magnetic pulses to specific brain regions to modulate neural activity. It is widely used both for therapeutic purposes (e.g., treating major depressive disorder) and for research into cognitive and linguistic processes. The effects of rTMS vary depending on stimulation parameters such as frequency, intensity, and the targeted brain region.

well as literal sentences. The findings revealed that the left hemisphere is more involved in processing opaque idioms, indicating that idiom transparency influences hemispheric specialization in figurative language comprehension. This study not only reinforces the importance of the DLPFC in understanding idiomatic expressions but also calls for further research into how different characteristics of idioms, such as transparency, influence neural processing during language comprehension.

Overall literature supports the hypothesis that different characteristics of idioms, such as their familiarity and whether they are used in a literal or figurative context, activate distinct brain regions. Specifically, familiar idioms and those used in a figurative context are more likely to engage the left hemisphere, while less familiar idioms and those used in a literal context tend to engage the RH. This hemispheric specialization in figurative language comprehension underscores the complexity of neural processing involved in pragmatic language skills. Besides idioms, Pobric et al., (2008) used rTMS to explore the role of RH in processing novel metaphoric expressions. The study showed that disrupting RH activity impaired the comprehension of novel metaphors, but not conventional ones, suggesting that the RH is crucial for integrating broader, less salient meanings in metaphor comprehension. The study highlighted the RH's specialized role in understanding novel metaphoric language.

In addition to TMS, tDCS has also been employed to investigate the neural mechanisms of idiom comprehension. For example, Sela et al. (2012) used tDCS to modulate neural excitability in the bilateral DLPFC and found that enhancing left DLPFC activity while inhibiting right DLPFC activity improved participants' ability to relate idioms to their figurative meanings. This study suggests that the left DLPFC plays a crucial role in inhibiting the literal meanings of idioms, thereby facilitating their figurative interpretation. A similar latter study, Mitchell et al., (2016) explored the role of the DLPFC in idiom processing using tDCS, finding that the left hemisphere DLPFC is particularly involved in figurative language processing, while both hemispheres contribute to literal language processing. The findings suggest that complex non-literal language processing, like idioms, requires domain-general cognitive control, especially in the suppression of incorrect meanings. While both studies investigate the role of the DLPFC in idiom processing using tDCS, Sela et al. (2012) adds a layer of complexity by examining how motivational factors interact with these cognitive control processes whereas Mitchell et al. (2016) explore hemispheric differences in cognitive control during both figurative and literal language processing. A most recent tDCS study (Lifshitz-Ben-Basat, & Mashal 2021), examined the effects of tDCS over the left angular gyrus (AG) on metaphor generation, revealing that cathodal stimulation enhanced novel metaphor creation, while anodal stimulation increased conventional metaphor generation. The authors suggested that cathodal tDCS may enhance creativity by reducing control network activity, highlighting the left AG's role in verbal creativity and novel metaphor generation. Overall, the existing body of research highlights the significant role of the DLPFC and other relevant brain regions in non-literal language processing.

2.2 Indirect Speech Acts

Most research on pragmatic language frequently examines non-literal language, such as metaphors, idioms, and irony, but another important focus within this domain is on indirect speech acts. Indirect speech acts, such as indirect requests, occur when a speaker's intention is not explicitly stated but is inferred by the listener based on context, shared knowledge, and social norms. The speech acts differ from direct communication, where the intention is plainly expressed, and instead require the listener to interpret the underlying meaning through additional cognitive effort. Speech acts, in general, are defined as linguistic units used to convey a person's intention, extending beyond the mere transmission of information in a communicative context. For example, when someone asks, “Did you finish your article?” and the response is, “I was up all night working on it,” the listener implicitly understands that the article was completed, even though this was not directly stated. The assumption that staying up all night is typically associated with finishing work is an example of how shared cultural knowledge and context facilitate the comprehension of indirect speech acts. In everyday communication, people frequently rely on indirect speech to navigate social interactions smoothly, often using this form of communication to maintain politeness, mitigate face-threatening acts, or subtly convey messages. However, understanding these indirect speech acts often demands more cognitive resources compared to direct speech. This is because the listener must engage in inferential reasoning, drawing on contextual clues and social expectations to grasp the intended meaning. As a result, many behavioral studies on the processing of speech acts have found that understanding indirect speech acts generally takes longer and requires more cognitive effort than understanding direct speech acts (Jang et al., 2013; Shibata et al., 2011; Feng et al., 2017, 2021; Hamblin and Gibbs, 2003; Holtgraves, 1999).

Recent advances in neurocognitive research have provided deeper insights into the mechanisms underlying the processing of speech acts. In a comprehensive review, Tomasello (2023) explored how the brain processes speech acts. Tomasello concluded that distinct cortical regions are responsible for processing various pragmatic features, such as ToM, emotional understanding, and action-related cues. This aligns with neurocognitive models (Lakoff 1987) suggesting that understanding speech acts involves not only linguistic decoding but also anticipating typical responses from communication partners. This anticipation is reflected in brain activity, indicating that the brain prepares for possible outcomes during communication, which is particularly relevant in indirect speech acts where the intended meaning is not directly stated.

The connection between indirect speech acts and ToM has been extensively studied in both healthy individuals and clinical populations. ToM plays a crucial role in understanding indirect speech acts as it refers to the ability to attribute mental states—such as beliefs, intentions, and desires—to oneself and others. Numerous studies (Trott & Bergen, 2019; Champagne-Lavau and Joanette, 2009; Champagne-Lavau and Stip, 2010) have observed that understanding indirect requests in speech acts is closely linked to ToM processes, as these require the listener to infer the speaker's intention based on their perspective and social context. A recent neurostimulation study have further explored the neural underpinnings of indirect speech act comprehension by targeting brain regions involved in ToM. Boux and Pulvermüller (2023) used rTMS to disrupt activity in the right temporo-parietal junction (rTPJ), a key brain region for ToM functions, to investigate its role in processing indirect speech acts. Their study involved comparing the effects of TMS on the comprehension of indirect speech acts and matched direct controls. When indirect and direct speech acts were matched for speech act type (both being statements), indirect ones consistently took longer to process. However, when they were not matched for communicative function (e.g., offer acceptance vs. descriptive statement), the delay was observed following sham TMS[2] but not after active TMS. This suggests that while rTPJ might not be directly involved in comprehending indirectness per se, it may play a role in the specific social communicative functions such as accepting or rejecting offers, or in handling the combination of different directness levels and communicative functions. The study concluded that ToM processing in the rTPJ might be more critical for certain types of communicative functions, such as offer acceptance or rejection, than for others (Boux & Pulvermüller 2023). Similarly, Feng et al. (2021) conducted a study using tDCS targeting the rTPJ to further investigate its role in understanding indirect speech acts. The study found that tDCS-induced modulation of rTPJ activity influenced performance on both indirect speech act comprehension tasks and ToM tasks. The analysis suggested that changes in the ability to understand indirect speech acts were mediated by ToM functions, reinforcing the idea that the rTPJ plays a crucial role in integrating social and linguistic information during communication.

[2] Sham TMS (Transcranial Magnetic Stimulation) is a placebo-controlled version of real TMS. In this method, the device is placed on the scalp similarly to real TMS, but no actual magnetic stimulation is applied. Sham TMS is used in research to differentiate the effects of treatment from placebo effects.

Both TMS and tDCS studies converge on the importance of the rTPJ in processing indirect speech acts, though they reveal nuanced differences in how this brain region contributes. While TMS studies suggest that rTPJ involvement may be more related to specific communicative functions like offer acceptance or rejection, tDCS studies indicate that modulation of rTPJ activity can directly influence the understanding of indirect speech through its impact on ToM processes. This growing body of research underscores the complexity of indirect speech act comprehension and highlights the interplay between linguistic, cognitive, and social factors in effective communication. Despite these advancements, research on the neural mechanisms underlying indirect speech acts remains relatively limited compared to studies on non-literal language. Given the critical role that indirect speech plays in everyday communication, there is a clear need for further studies to expand our understanding of how the brain processes these complex pragmatic functions.

2.3 Social Communication

Another crucial aspect of pragmatic language is decision-making during communication, particularly in varying social contexts. Effective communication often necessitates that individuals make strategic decisions regarding what to say, how to say it, and when to say it, all based on the social context and perceived expectations of the listener. These decisions are not merely about word choice but also selecting the appropriate tone, level of formality, and even the amount of information to share. For instance, in a formal setting, a speaker might choose to use more polite, precise, and structured language, while in an informal setting, the same speaker may opt for a relaxed, colloquial tone. The speaker's understanding of social norms, the nature of their relationship with the listener, and the desired outcome of the interaction heavily influence these communicative decisions. This complex decision-making process is supported by neural mechanisms that integrate social, cognitive, and linguistic information. Research in this area is still emerging, but it is critical to understanding the neurobiological underpinnings of pragmatic language. Martin-Luengo et al. (2023) conducted a study to investigate the neural substrates supporting decision-making in communication across different social contexts. They specifically explored the role of the left middle frontal gyrus (lMFG) in regulating communicative decisions under social pressure, using rTMS. Participants were divided into three groups: (i) receiving rTMS to the lMFG, (ii) to the right MFG as an active control, and (iii) receiving sham stimulation. Participants were asked to answer difficult general-knowledge questions, rate their confidence in their answers, and decide whether to report or withhold these answers depending on whether they were in a formal or informal context. The study revealed that inhibition of the lMFG led to participants withholding more answers in a formal context, suggesting that this brain region plays a critical role in regulating communicative decisions when social stakes are high. This indicates that the lMFG may be involved in assessing the potential social consequences of sharing information, particularly when there is a risk associated with being wrong. Participants in the study adjusted their communication strategies based on their confidence in the correctness of their answers and their perception of the informativeness of their responses. This highlights the dynamic interplay between cognitive processes, such as self-assessment and social evaluation, and the broader social dynamics that shape how we communicate in different settings. These findings add to our understanding of how the brain manages the complex demands of social communication, particularly in decision-making processes that require balancing accuracy, confidence, and social appropriateness. While Martin-Luengo et al (2023) focused on the role of the lMFG in these processes, other regions of the brain also contribute to how we navigate social interactions and make communicative decisions. Another study, Osovlanski & Mashal (2017) explored how tDCS over the left superior temporal gyrus (STG) influences sentence processing, particularly in sentences with semantic and pragmatic violations. Using a violation paradigm, participants listened to sentences containing either semantic or pragmatic violations and were asked to judge whether these sentences "made sense." The study found that response times to sentences with pragmatic violations were significantly faster after active tDCS stimulation compared to sham stimulation, indicating that tDCS enhances pragmatic processing. However, the same stimulation did not affect the processing of semantic violations, suggesting that distinct neural mechanisms are at play in processing semantic versus pragmatic information. These findings underscore the importance of the left STG in processing real-world knowledge, further highlighting the different cognitive demands involved in comprehending sentences that violate semantic versus pragmatic expectations. This study further suggests potential applications of tDCS in enhancing pragmatic language processing, particularly for individuals with language comprehension difficulties, such as those seen in autism or schizophrenia. However, the study also points to the need for further research to confirm these effects in larger populations and clinical settings, emphasizing the broader implications for improving pragmatic language skills through neuromodulation. Despite these important findings, it is worth noting that research on the role of TMS and tDCS in pragmatic language, particularly in decision-making during communication, remains relatively scarce, especially in studies involving healthy individuals. However, there is a growing body of research focusing on these techniques in the context of autism spectrum disorder (Schneider & Hopp, 2011, for review see Massoni, 2024), where pragmatic language impairments are more pronounced. The complexity of social communication and the nuances required in making context-appropriate decisions underscore the need for more targeted research to fully understand the underlying neural mechanisms.

2.4 Gesture-Speech Integration

In natural conversations, language conveys only a portion of the information being communicated. Communication is a rich, multimodal process where nonverbal signals, such as hand and arm movements, facial expressions, shifts in gaze, and changes in posture, play a crucial role in the overall exchange of information. These nonverbal cues can significantly enhance the spoken message, adding layers of meaning that may not be conveyed through words alone. Sometimes, nonverbal signals can even alter the intended meaning of a verbal message, creating nuances that would otherwise be lost in a purely verbal exchange. For instance, a slight smile or a raised eyebrow can transform a simple statement into one laden with sarcasm or irony, conveying a meaning entirely different from the literal words spoken. Among these nonverbal cues, co-speech gestures—gestures that accompany speech—have been the focus of extensive research due to their pivotal role in communication. Co-speech gestures are spontaneous, often subconscious movements that speakers use to emphasize, illustrate, or complement their spoken words. These gestures are deeply integrated into our communication patterns and are thought to arise from the same cognitive processes that generate speech. They can help clarify complex ideas, reinforce the message being conveyed, or even express emotions that words alone might struggle to communicate.

The integration of speech and gestures, known as speech-gesture integration, involves the simultaneous processing of verbal communication and non-verbal cues, enabling a more effective and nuanced exchange of information. This integration is vital for listeners to infer speakers' intentions, contextualize the spoken content, and grasp the broader meaning of the conversation. Gestures can provide additional context that helps listeners decode the speaker’s message more accurately, especially in cases where the verbal information might be ambiguous or incomplete. This process is a key element of pragmatic language, which is concerned with the use of language in social contexts and the interpretation of meaning beyond the literal content of words. The process of integrating speech and gestures enhances pragmatic language use by providing additional contextual and social cues that make communication more effective. For example, a gesture indicating the size of an object while describing it verbally allows the listener to visualize and better understand the description, thereby enhancing comprehension. This multimodal approach to communication ensures that the speaker’s message is conveyed more clearly, and that the listener can engage more fully with the content.

Neuroimaging research on the integration of speech and gestures consistently highlights the importance of specific brain regions in this process. Two regions, the inferior frontal gyrus (IFG) and the posterior middle temporal gyrus (pMTG), have been shown to be crucial, typically displaying a left hemisphere bias (Dick et al., 2014; Straube et al., 2012; Willems et al., 2007). The IFG, which includes Broca's area, is traditionally associated with language production and syntactic processing, while the pMTG is linked to semantic processing and the integration of multimodal information. These regions are believed to facilitate the seamless integration of verbal and non-verbal communication, ensuring that the combined message is coherent and contextually appropriate. The involvement of these areas underscores the brain's ability to manage complex communicative tasks that require the coordination of multiple cognitive processes.

One of the early studies in this area, conducted by Gentilucci et al. (2006), investigated the role of Broca's area in integrating verbal responses with observed gestures using rTMS. Low-frequency rTMS[3] was applied to both the left hemisphere (targeting Broca's area) and the RH (targeting Broca's homologue) while participants responded verbally to communicative words and gestures. The study indicates that Broca's area is critical for translating the representations of arm gestures into verbal articulation. Specifically, stimulation of the left hemisphere disrupted the usual enhancement of verbal responses to gestures, suggesting that Broca's area plays a pivotal role in processing the social intentions encoded by gestures. These results support the theory that spoken language may have evolved from a gestural communication system (Gesture-First Hypothesis, Hewes, 1973; Armstrong, Stokoe, and Wilcox, 1995) highlighting the intertwined nature of verbal and non-verbal communication in the brain. The study also suggests that Broca's area might be more broadly involved in processing the pragmatic aspects of communication, beyond its well-established role in syntax processing. A more recent study by Zhao et al. (2018) further explored the causal roles of the left inferior frontal gyrus (LIFG) and posterior middle pMTG in speech-gesture integration. The study aimed to address inconsistencies found in previous neuroimaging research regarding the involvement of these regions. They employed continuous theta burst stimulation (cTBS[4]) and rTMS to these regions to observe the effects on semantic

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[3] Low-frequency repetitive Transcranial Magnetic Stimulation delivers magnetic pulses at ≤1 Hz and is primarily used to suppress activity in targeted cortical regions. In linguistic research, it is often employed to investigate the role of specific brain regions in language processing by temporarily inhibiting their activity, thus providing insights into their functional contributions.

[4] Continuous theta burst stimulation is a form of repetitive transcranial magnetic stimulation (rTMS) that uses short bursts of magnetic pulses at a high frequency, typically in the theta rhythm, to modulate brain activity. cTBS is often employed to induce long-

congruency during speech-gesture tasks. The results revealed that disrupting left IFG activity reduced the semantic congruency effect, indicating its essential role in integrating speech and gestures. This finding aligns with the idea that the IFG, particularly in the left hemisphere, plays a critical role in the higher-order cognitive processes required for combining verbal and non-verbal information into a unified communicative act. In contrast, disruption of the pMTG did not yield the same effect, suggesting that this region may have a different or complementary function in the integration process, possibly related to the retrieval and integration of semantic information from memory. These studies collectively illustrate the complexity of speech-gesture integration and its importance in effective communication. By understanding how the brain coordinates these processes, researchers can gain insights into the neural mechanisms that underpin pragmatic language use. This knowledge has practical implications for enhancing communication strategies, especially in educational settings, therapy for individuals with language impairments, and even in designing more effective communication technologies. Despite these advances, it is important to recognize that research on the neural underpinnings of speech-gesture integration, particularly using TMS and tDCS, remains limited. Much of the current knowledge comes from neuroimaging studies, and while these provide valuable insights, they often cannot establish causal relationships between brain regions and specific cognitive functions. TMS and tDCS offer the potential to explore these causal relationships more directly, but more extensive research is needed to fully understand how these brain regions contribute to the integration of speech and gestures. Expanding this research could lead to significant advancements in both our theoretical understanding of communication and its practical applications in various fields.

3 Conclusion and Future Directions

The expanding field of research utilizing TMS and tDCS has significantly advanced the understanding of the neural mechanisms of language processing. These NIBS techniques allow researchers to manipulate brain activity and study the functional contributions of various brain regions to complex cognitive tasks. The strength of both TMS and tDCS lies in their ability to provide causal evidence for the role of specific brain regions in these cognitive functions. In addition to investigating neural correlates, neurostimulation techniques have been used as therapeutic interventions to enhance pragmatic language skills by targeting the pragmatic language-related brain regions. By modulating brain activity, these techniques can facilitate better understanding of social cues and

lasting changes in neural excitability and has been used in various studies to explore its effects on cognitive functions and brain networks associated with language processing.

improve overall communication effectiveness. Pragmatic language, which includes non-literal language comprehension, indirect speech acts, social communication, and gesture-speech integration, involves complex cognitive processes that extend beyond basic linguistic functions. These processes require the integration of social cues, context, and shared knowledge, which are essential for effective communication.

This review highlights key insights into the neural mechanisms underlying pragmatic language, synthesized from studies utilizing TMS and tDCS. The findings reveal the critical involvement of the DLPFC in managing non-literal language, such as idiomatic expressions, primarily through its role in cognitive control. Similarly, the rTPJ emerges as indispensable for interpreting indirect speech acts, leveraging Theory of Mind to decipher speaker intentions. The left MFG contributes significantly to decision-making in communication, particularly under social constraints, while the left IFG and pMTG play central roles in integrating gestures with speech. Collectively, these results not only underscore the complexity of pragmatic language processing but also establish a foundational framework for further exploration in this domain.

Despite these promising findings, research on the application of TMS and tDCS in pragmatic language rehabilitation remains relatively sparse, particularly in clinical populations. However, the insights gained from studies on healthy individuals can serve as a valuable foundation for developing targeted neuromodulation interventions in clinical settings.

Furthermore, studies exploring the clinical applications of these techniques have the potential to transform therapeutic practices for individuals with pragmatic language impairments. Targeted interventions using TMS and tDCS may offer personalized treatment options for clinical populations such as individuals with autism spectrum disorder, traumatic brain injury, or neurodegenerative diseases. For example, modulating the rTPJ may enhance the understanding of indirect speech acts in individuals with ASD, while stimulating the DLPFC may help individuals with traumatic brain injury improve their ability to process non-literal language. Moreover, integrating these techniques with behavioral therapies may improve their efficacy in treating pragmatic language deficits.

The results of linguistic studies involving TMS and tDCS have significant clinical implications. Clinical populations often struggle with language and communication deficits, and the insights gained from these studies could provide essential guidance for effective intervention strategies. The application of TMS and tDCS in clinical contexts offers the possibility of targeted, evidence-based therapies that can help address specific pragmatic language impairments. As a result, increasing research-based TMS and tDCS applications is crucial for developing effective interventions in clinical practice. Expanding research in this field will not only deepen our understanding of the neural mechanisms underlying pragmatic language but also pave the way for more effective rehabilitation strategies for individuals facing communication challenges.

In summary, while TMS and tDCS have already contributed significantly to our understanding of pragmatic language processing, there is a clear need for further research to explore their full potential in both theoretical and clinical contexts. By continuing to investigate these techniques, we can hope to develop more effective, evidence-based interventions that improve the quality of life for individuals with pragmatic language impairments.

While this review has focused on specific aspects of pragmatic language—namely, non-literal language, indirect speech acts, social communication, and gesture-speech integration—it is important to acknowledge that pragmatic language encompasses additional components such as topic maintenance, prosody, and purposeful communication. These aspects were not covered in the current review, primarily due to the limited number of neurostimulation studies addressing them. This constitutes a limitation of the present study and highlights an avenue for future research. Expanding neurostimulation investigations to include these underexplored dimensions will contribute to a more comprehensive understanding of the neural mechanisms underlying pragmatic language processing. Future research should aim to broaden the scope of neurostimulation investigations to include these aspects, thereby providing a more comprehensive understanding of the neural underpinnings of pragmatic language processing.

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References

Arcara, G., Tonini, E., Muriago, G., Mondin, E., Sgarabottolo, E., Bertagnoni, G., & Bambini, V. (2020). Pragmatics and figurative language in individuals with traumatic brain injury: Fine-grained assessment and relevance-theoretic considerations. Aphasiology, 34(8), 1070-1100.

Armstrong, D., Stokoe, W. and Wilcox, S. (1995) Gesture and the Nature of Language. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511620911

Bambini, V., Gentili, C., Ricciardi, E., Bertinetto, P. M., & Pietrini, P. (2011). Decomposing metaphor processing at the cognitive and neural level through functional magnetic resonance imaging. Brain research bulletin, 86(3-4), 203-216.

Bambini, V., Tonini, E., Ceccato, I., Lecce, S., Marocchini, E., & Cavallini, E. (2020). How to improve social communication in aging: Pragmatic and cognitive interventions. Brain and Language, 211, 104864.

Bambini, V., Van Looy, L., Demiddele, K., & Schaeken, W. (2021). What is the contribution of executive functions to communicative-pragmatic skills? Insights from aging and different types of pragmatic inference. Cognitive processing, 22(3), 435-452.

Barker AT, Jalinous R, Freeston IL (1985) Noninvasive magnetic stimulation of human motor cortex. Lancet 1:1106–1107.

Bosco, F. M., Parola, A., Sacco, K., Zettin, M., & Angeleri, R. (2017). Communicative-pragmatic disorders in traumatic brain injury: The role of theory of mind and executive functions. Brain and language, 168, 73-83.

Bottini, G., Corcoran, R., Sterzi, R., Paulesu, E., Schenone, P., Scarpa, P., ... & Frith, D. (1994). The role of the right hemisphere in the interpretation of figurative aspects of language A positron emission tomography activation study. Brain, 117(6), 1241-1253.

Boux, I. P., & Pulvermüller, F. (2023). Does the right temporo-parietal junction play a role in processing indirect speech acts? A transcranial magnetic stimulation study. Neuropsychologia, 176, Article 108295.

Brownell, H. H., Simpson, T. L., Bihrle, A. M., Potter, H. H., & Gardner, H. (1990). Appreciation of metaphoric alternative word meanings by left and right brain-damaged patients. Neuropsychologia, 28(4), 375-383.

Cacciari, C., & Glucksberg, S. (1995). Understanding idioms: Do visual images reflect figurative meanings?. European Journal of Cognitive Psychology, 7(3), 283-305.

Cardillo, E. R., McQuire, M., & Chatterjee, A. (2018). Selective metaphor impairments after left, not right, hemisphere injury. Frontiers in psychology, 9, 2308.

Champagne-Lavau, M., & Joanette, Y. (2009). Pragmatics, theory of mind and executive functions after a right-hemisphere lesion: Different patterns of deficits. Journal of neurolinguistics, 22(5), 413-426.

Champagne-Lavau, M., & Stip, E. (2010). Pragmatic and executive dysfunction in schizophrenia. Journal of Neurolinguistics, 23(3), 285-296.

Corcoran, R., Mercer, G., & Frith, C. D. (1995). Schizophrenia, symptomatology and social inference: investigating "theory of mind" in people with schizophrenia. Schizophrenia research, 17(1), 5-13.

Dennis, M., Lazenby, A. L., & Lockyer, L. (2001). Inferential language in high-function children with autism. Journal of autism and developmental disorders, 31, 47-54.

Devlin, J. T., & Watkins, K. E. (2007). Stimulating language: insights from TMS. Brain, 130(3), 610-622.

Dick, A. S., Mok, E. H., Beharelle, A. R., Goldin-Meadow, S., & Small, S. L. (2014). Frontal and temporal contributions to understanding the iconic co-speech gestures that accompany speech. Human brain mapping, 35(3), 900-917.

Feng, W., Wu, Y., Jan, C., Yu, H., Jiang, X., & Zhou, X. (2017). Effects of contextual relevance on pragmatic inference during conversation: An fMRI study. Brain and Language, 171, 52-61.

Feng, W., Yu, H., & Zhou, X. (2021). Understanding particularized and generalized conversational implicatures: Is theory-of-mind necessary?. Brain and Language, 212, 104878.

Ferré P, Fonseca RP, Ska B, & Joanette Y (2012). Communicative clusters after a right-hemisphere stroke: are there universal clinical profiles? Folia Phoniatrica et Logopaedica, 64(4), 199–207. 10.1159/000340017

Fernández, C. (2013). Mindful storytellers: Emerging pragmatics and theory of mind development. First Language, 33(1), 20-46.

Ferstl, E. C., Neumann, J., Bogler, C., & Von Cramon, D. Y. (2008). The extended language network: a meta-analysis of neuroimaging studies on text comprehension. Human brain mapping, 29(5), 581-593.

Flöel, A. (2012). Non-invasive brain stimulation and language processing in the healthy brain. Aphasiology, 26(9), 1082-1102.

Flöel, A., Rösser, N., Michka, O., Knecht, S., & Breitenstein, C. (2008). Noninvasive brain stimulation improves language learning. Journal of cognitive neuroscience, 20(8), 1415-1422.

Fogliata, A., Rizzo, S., Reati, F., Miniussi, C., Oliveri, M., & Papagno, C. (2007). The time course of idiom processing. Neuropsychologia, 45(14), 3215-3222.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 358(1431), 459-473.

Galletta, E. E., Rao, P. R., & Barrett, A. M. (2011). Transcranial magnetic stimulation (TMS): potential progress for language improvement in aphasia. Topics in stroke rehabilitation, 18(2), 87-91.

Gentilucci, M., Bernardis, P., Crisi, G., & Volta, R. D. (2006). Repetitive transcranial magnetic stimulation of Broca's area affects verbal responses to gesture observation. Journal of Cognitive Neuroscience, 18(7), 1059-1074.

Gibson, L., Atchley, R. A., Voyer, D., Diener, U. S., & Gregersen, S. (2016). Detection of sarcastic speech: The role of the right hemisphere in ambiguity resolution. Laterality: Asymmetries of Body, Brain and Cognition, 21(4-6), 549-567.

Hage, S. V. R., Sawasaki, L. Y., Hyter, Y., & Fernandes, F. D. M. (2021, December). Social communication and pragmatic skills of children with autism spectrum disorder and developmental language disorder. In CoDAS (Vol. 34, No. 2, p. e20210075). Sociedade Brasileira de Fonoaudiologia.

Hallett, M. (2007). Transcranial magnetic stimulation: a primer. Neuron, 55(2), 187-199.

Häuser, K. I., Titone, D. A., & Baum, S. R. (2016). The role of the ventro-lateral prefrontal cortex in idiom comprehension: An rTMS study. Neuropsychologia, 91, 360-370.

Hamblin, J. L., & Gibbs Jr, R. W. (2003). Processing the meanings of what speakers say and implicate. Discourse Processes, 35(1), 59-80.

Hartwigsen, G., & Siebner, H. R. (2012). Probing the involvement of the right hemisphere in language processing with online transcranial magnetic stimulation in healthy volunteers. Aphasiology, 26(9), 1131-1152.

Hauptman, M., Blank, I., & Fedorenko, E. (2023). Non-literal language processing is jointly supported by the language and theory of mind networks: evidence from a novel meta-analytic fMRI approach. Cortex, 162, 96-114.

Hewes, G. W. (1973). An explicit formulation of the relationship between tool-using, tool-making, and the emergence of language. Visible Language, 7(2), 101-127.

Holtgraves, T. (1999). Comprehending indirect replies: When and how are their conveyed meanings activated?. Journal of Memory and Language, 41(4), 519-540.

Holtgraves, T., & McNamara, P. (2010). Pragmatic comprehension deficit in Parkinson's disease. Journal of Clinical and Experimental Neuropsychology, 32(4), 388-397.

Iyer, M. B., Mattu, U., Grafman, J., Lomarev, M., Sato, S., & Wassermann, E. M. (2005). Safety and cognitive effect of frontal DC brain polarization in healthy individuals. Neurology, 64(5), 872-875.

Jang, G., Yoon, S. A., Lee, S. E., Park, H., Kim, J., Ko, J. H., & Park, H. J. (2013). Everyday conversation requires cognitive inference: Neural bases of comprehending implicated meanings in conversations. NeuroImage, 81, 61-72.

Kurada, H. Z., Arıca-Akkök, E., Özaydın-Aksun, Z., Şener, H. Ö., & Lavidor, M. (2021). The impact of transparency on hemispheric lateralization of idiom comprehension: An rTMS study. Neuropsychologia, 163, 108062.

Lee, S. S., & Dapretto, M. (2006). Metaphorical vs. literal word meanings: fMRI evidence against a selective role of the right hemisphere. NeuroImage, 29(2), 536-544.

Levinson, S. C. (2016). Turn-taking in human communication–origins and implications for language processing. Trends in cognitive sciences, 20(1), 6-14.

Lifshitz-Ben-Basat, A., & Mashal, N. (2021). Enhancing creativity by altering the frontoparietal control network functioning using transcranial direct current stimulation. Experimental Brain Research, 239, 613-626.

Lindell, A. K. (2006). In your right mind: Right hemisphere contributions to language processing and production. Neuropsychology review, 16(3), 131-148.

Lundgren, K., Brownell, H., Roy, S., & Cayer-Meade, C. (2006). A metaphor comprehension intervention for patients with right hemisphere brain damage: A pilot study. Brain and Language, 99(1-2), 69-70.

Pisano, F., & Marangolo, P. (2020). Looking at ancillary systems for verb recovery: Evidence from non-invasive brain stimulation. Brain and Cognition, 139, 105515.

Martín-Luengo, B., Vorobiova, A. N., Feurra, M., Myachykov, A., & Shtyrov, Y. (2023). Transcranial magnetic stimulation of the left middle frontal gyrus modulates the information people communicate in different social contexts. Scientific Reports, 13(1), 9995.

Martín-Rodríguez, J. F., & León-Carrión, J. (2010). Theory of mind deficits in patients with acquired brain injury: A quantitative review. Neuropsychologia, 48(5), 1181-1191.

Massoni, L. (2024). Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (TDCS) in Autism Spectrum Disorder. Med Discoveries, 3(1), 1107

McDonald, S. (2000). Exploring the cognitive basis of right-hemisphere pragmatic language disorders. Brain and language, 75(1), 82-107.

Minga, J., Sheppard, S. M., Johnson, M., Hewetson, R., Cornwell, P., & Blake, M. L. (2023). Apragmatism: The renewal of a label for communication disorders associated with right hemisphere brain damage. International journal of language & communication disorders, 58(2), 651-666.

Mitchell, R. L., Vidaki, K., & Lavidor, M. (2016). The role of left and right dorsolateral prefrontal cortex in semantic processing: A transcranial direct current stimulation study. Neuropsychologia, 91, 480-489.

Mitchell, W. J. (2009). Visual literacy or literary visualcy?. In Visual literacy (pp. 19-38). Routledge.

Mitchley, N. J., Barber, J., Gray, J. M., Brooks, D. N., & Livingston, M. G. (1998). Comprehension of irony in schizophrenia. Cognitive Neuropsychiatry, 3(2), 127-138.

Monti, A., Ferrucci, R., Fumagalli, M., Mameli, F., Cogiamanian, F., Ardolino, G., & Priori, A. (2013). Transcranial direct current stimulation (tDCS) and language. Journal of Neurology, Neurosurgery & Psychiatry, 84(8), 832-842.

Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. The Journal of physiology, 527(Pt 3), 633.

Nitsche, M. A., Seeber, A., Frommann, K., Klein, C. C., Rochford, C., Nitsche, M. S., ... & Tergau, F. (2005). Modulating parameters of excitability during and after transcranial direct current stimulation of the human motor cortex. The Journal of physiology, 568(1), 291-303.

Noveck, I. (2018). Experimental pragmatics: The making of a cognitive science. Cambridge University Press.

Ntemou, E., Svaldi, C., Jonkers, R., Picht, T., & Rofes, A. (2023). Verb and sentence processing with TMS: a systematic review and meta-analysis. cortex, 162, 38-55.

Oliveri, M., Romero, L., & Papagno, C. (2004). Left but not right temporal involvement in opaque idiom comprehension: A repetitive transcranial magnetic stimulation study. Journal of cognitive Neuroscience, 16(5), 848-855.

Osovlanski, H., & Mashal, N. (2017). The effects of transcranial direct current stimulation on pragmatic processing. Journal of Neurolinguistics, 44, 239-248.

Pascual-Leone, A. (1999). Transcranial magnetic stimulation: studying the brain--behaviour relationship by induction of 'virtual lesions'. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 354(1387), 1229-1238.

Pascual-Leone, A., Valls-Solé, J., Wassermann, E. M., & Hallett, M. (1994). Responses to rapid-rate transcranial magnetic stimulation of the human motor cortex. Brain, 117(4), 847-858.

Pascual-Leone, A., Walsh, V., & Rothwell, J. (2000). Transcranial magnetic stimulation in cognitive neuroscience–virtual lesion, chronometry, and functional connectivity. Current opinion in neurobiology, 10(2), 232-237.

Pascual-Leone, A., Gates, J. R., & Dhuna, A. (1991). Induction of speech arrest and counting errors with rapid-rate transcranial magnetic stimulation. Neurology, 41(5), 697-702.

Pijnacker, J., Vervloed, M. P., & Steenbergen, B. (2012). Pragmatic abilities in children with congenital visual impairment: An exploration of non-literal language and advanced theory of mind understanding. Journal of autism and developmental disorders, 42, 2440-2449.

Pobric, G., Mashal, N., Faust, M., & Lavidor, M. (2008). The role of the right cerebral hemisphere in processing novel metaphoric expressions: a transcranial magnetic stimulation study. Journal of cognitive neuroscience, 20(1), 170-181.

Rapp, A. M., & Wild, B. (2011). Nonliteral language in Alzheimer dementia: a review. Journal of the International Neuropsychological Society, 17(2), 207-218.

Rapp, A. M., Leube, D. T., Erb, M., Grodd, W., & Kircher, T. T. (2004). Neural correlates of metaphor processing. Cognitive brain research, 20(3), 395-402.

Reindal, L., Nærland, T., Weidle, B., Lydersen, S., Andreassen, O. A., & Sund, A. M. (2021). Structural and pragmatic language impairments in children evaluated for autism spectrum disorder (ASD). Journal of Autism and Developmental Disorders, 1-19.

Rizzo, S., Sandrini, M., & Papagno, C. (2007). The dorsolateral prefrontal cortex in idiom interpretation: An rTMS study. Brain research bulletin, 71(5), 523-528.

Rowley, D. A., Rogish, M., Alexander, T., & Riggs, K. J. (2017). Cognitive correlates of pragmatic language comprehension in adult traumatic brain injury: A systematic review and meta-analyses. Brain injury, 31(12), 1564-1574.

Sakın, B. (2021). Pragmatic language disorders resulting from semantic degradation in patients with Alzheimer's disease. Clinical and Experimental Health Sciences, 11(3), 523-528.

Sela, T., Ivry, R. B., & Lavidor, M. (2012). Prefrontal control during a semantic decision task that involves idiom comprehension: a transcranial direct current stimulation study. Neuropsychologia, 50(9), 2271-2280.

Schneider, H. D., & Hopp, J. P. (2011). The use of the Bilingual Aphasia Test for assessment and transcranial direct current stimulation to modulate language acquisition in minimally verbal children with autism. Clinical linguistics & phonetics, 25(6-7), 640-654.

Shamay-Tsoory, S. G., Tomer, R., Yaniv, S., & Aharon-Peretz, J. (2002). Empathy deficits in Asperger syndrome: A cognitive profile. Neurocase, 8(3), 245-252.

Shammi, P., & Stuss, D. T. (1999). Humour appreciation: a role of the right frontal lobe. Brain, 122(4), 657-666.

Sheppard SM, Meier EL, Durfee AZ, Walker A, Shea J, & Hillis AE (2021). Characterizing subtypes and neural correlates of receptive aprosodia in acute right hemisphere stroke. Cortex, 141, 36–54.

Shibata, M., Abe, J. I., Itoh, H., Shimada, K., & Umeda, S. (2011). Neural processing associated with comprehension of an indirect reply during a scenario reading task. Neuropsychologia, 49(13), 3542-3550.

Shibata, M., Toyomura, A., Itoh, H., & Abe, J. I. (2010). Neural substrates of irony comprehension: A functional MRI study. Brain research, 1308, 114-123.

Spotorno, N., Koun, E., Prado, J., Van Der Henst, J. B., & Noveck, I. A. (2012). Neural evidence that utterance-processing entails mentalizing: The case of irony. NeuroImage, 63(1), 25-39.

Straube, B., Green, A., Weis, S., & Kircher, T. (2012). A supramodal neural network for speech and gesture semantics: an fMRI study. PloS one, 7(11), e51207.

Stemmer, B. (2008). Neuropragmatics. The handbook of clinical linguistics, 61-78.

Tomasello, R. (2023). Linguistic signs in action: The neuropragmatics of speech acts. Brain and Language, 236, 105203.

Torres, J., Drebing, D., & Hamilton, R. (2013). TMS and tDCS in post-stroke aphasia: Integrating novel treatment approaches with mechanisms of plasticity. Restorative Neurology and Neuroscience, 31(4), 501-515.

Trott, S., Reed, S., Ferreira, V., & Bergen, B. K. (2019). Prosodic cues signal the intent of potential indirect requests. In CogSci (pp. 1142-1148).

Weed E (2011). What's left to learn about right hemisphere damage and pragmatic impairment? Aphasiology, 25:8, 872–889, DOI: 10.1080/02687038.2010.545423 10.1006/brln.1997.1889

Willems, R. M., & Hagoort, P. (2007). Neural evidence for the interplay between language, gesture, and action: A review. Brain and language, 101(3), 278-289.

Winner, E., Brownell, H., Happé, F., Blum, A., & Pincus, D. (1998). Distinguishing lies from jokes: Theory of mind deficits and discourse interpretation in right hemisphere brain-damaged patients. Brain and language, 62(1), 89-106.

Zhao, W., Riggs, K., Schindler, I., & Holle, H. (2018). Transcranial magnetic stimulation over left inferior frontal and posterior temporal cortex disrupts gesture-speech integration. Journal of Neuroscience, 38(8), 1891-1900.