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The effects of transcranial direct current stimulation on pragmatic processing

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ABSTRACT

The current study used the violation paradigm to assess responses to pragmatically and semantically violated sentences. Thirteen participants received bilateral tDCS stimulation (anodal – left Superior Temporal Gyrus (STG) and cathodal – right STG). The participants listened to sentences with no violations as well as sentences with pragmatic or semantic violations and had to indicate whether each sentence "makes sense". This task was conducted in three conditions — without stimulation, after active stimulation, and after a sham procedure. The results showed faster response times for the pragmatic violations than for the semantic violations. The response times for the pragmatic violations after active stimulation were faster than after a sham stimulation. No similar difference in response times was observed for the semantic violations. These findings suggest that brain stimulation of the STG area modulates the processing of pragmatic but not semantic information.

1. Introduction

Understanding the meaning of a sentence relies on the integration of semantic and pragmatic information. Semantic processing is based on the meaning of the words and considered purely linguistic. There are semantic rules which are applied in sentence comprehension. Verbs have selection restriction properties (Chomsky, 1965) which dictate the types of noun that may follow these verbs. While the sentence "I convinced my mother" makes sense, we will not accept the sentence "I convinced my number" because the semantic selection restriction properties of the verb "convince" (i.e., that the object must be a person) are incongruent with the object "number". In contrast, pragmatics deals with the social aspects of communication. Pragmatic processing uses additional information that goes beyond the meaning of the words and is associated with knowledge about the world. In the current study, we use the term "pragmatic processing" in its narrow and specific sense, to refer to the use of "real world knowledge" to determine whether a sentence make sense (Kuperberg et al., 2000).

A well-established paradigm for studying semantic and pragmatic processing in sentence comprehension is the "violation paradigm". In this paradigm, participants read or hear correctly formed sentences intermixed with sentences that contain some sort of violation or incongruity of syntax, semantics or pragmatics. Several studies have used the term "pragmatic violations" in the same way that the present study uses the term "real-world knowledge violations" (Kuperberg, Sitnikova, & Lakshmanan, 2008; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003b; Kuperberg et al., 2003a; Marslen-Wilson, Brown, &

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Tyler, 1988; Paczynski & Kuperberg, 2012; Ye & Zhou, 2009). Marslen-Wilson et al. (1988) were the first to use sentences with such violations. The participants listened to normal sentences (e.g., *John played the guitar*) and to sentences with syntactic (e.g., *John slept the guitar*), semantic (e.g., *John drank the guitar*), or pragmatic (*John buried the guitar*) violations, and had to press a computer key when they heard the target word (e.g. *guitar*). Each sentence was preceded by a lead-in sentence that provided a context for it. The results showed slower response times to the sentences with the violations than the normal sentences. The responses to sentences with pragmatic violations were significantly faster than to sentences with semantic violations. However, a different pattern of responses was documented in a later study (Kuperberg et al., 2008), in which the participants had to indicate whether a sentence they read "made sense". The participants responded to sentences with syntactic violations (e.g. *Every morning at breakfast the boys would eats toast and jam*), pragmatic violations (e.g., *Every morning at breakfast the boys would plant the flowers*) and sentences with semantic violations (e.g., *Every morning at breakfast the eggs would eat toast and jam*). The problem in the sentences with pragmatic violations lies at the level of integrating the occasions when boys might plant flowers with what we know about events that usually occur at breakfast. The sentences with semantic violations are ungrammatical because the inanimate subject "eggs" does not have the semantic attributes to perform the action of eating. When encountering such a violation one has to continue the analysis or the reanalysis of the critical word in relation to its context. The results showed that response times to sentences with pragmatic violations were significantly slower than to sentences with semantic violations. In addition, the response times to the semantically violated sentences did not significantly differ from those for the non-violated sentences. The different methods – i.e., the type of the word in which the violation could be detected (a noun vs. a verb), the presence of a lead-in sentence, the location of the target word within the sentence and the type of task – may have contributed to the apparently contradictory results.

Evidence for behavioral differences in processing semantic and pragmatic violations were also observed in studies using other techniques. For instance, eye-movement tracking studies (Rayner, Warren, Juhasz, & Liversedge, 2004; Warren & McConnell, 2007) showed a difference in eye-movement patterns when people read sentences with semantic or pragmatic violations. Paczynski and Kuperberg (2012) found different event-related potential (ERP) waveforms for semantic and pragmatic violations. Both types of violations elicited an N400 waveform in response to the critical word. The N400 waveform is a negative-going potential with an onset at about 250 ms and a peak around 400 ms and is thought to reflect the semantic processing of a word in relation to its preceding context (Kutas & Federmeier, 2011). The semantic associates of the critical word in the preceding linguistic context attenuated the N400 response to the world-knowledge violations but did not attenuate the N400 response to the semantic violations. Those findings suggest that the brain distinguishes between the processing of real-world knowledge and semantic (selection-restriction) information during sentence comprehension.

Neuroimaging studies of pragmatic and semantic violations yielded inconsistent findings (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Kuperberg et al., 2008, 2000; Menenti, Petersson, Scheering, & Hagoort, 2009; Tesink, Buitelaar & Petersson, 2011; Ye & Zhou, 2009). Kuperberg et al. (2000) measured the neural activity of subjects listening to normal sentences in contrast to sentences containing pragmatic, semantic or syntactic violations. The participants were asked to judge whether the sentences "made sense". The violations were created by replacing the last word of the normal sentences (e.g., *My mother ironed a shirt*) with one that created a syntactic violation (e.g., *His father chattered the umbrella*), semantic violation (e.g., *My mother ironed a kiss*) or a pragmatic one (e.g., *The woman painted the insect*). Greater activation in the left superior-temporal gyrus (STG) was observed for the pragmatic condition than for either the normal, the semantic or the syntactic one, and there was greater activation of the right STG and middle-temporal gyrus (MTG) in the semantic than in the syntactic condition. A subsequent study compared the brain activity of subjects reading normal sentences or tones with syntactic or pragmatic violations (Kuperberg et al., 2003a). In that study the word creating the violation was a verb which was sentence-final (e.g. *for good photographs we hoped that the infant would phone*) or non-sentence-final (e.g. *If the post office is closed John cannot shoot the letter*). Greater activity in the left STG was found in response to sentences with pragmatic violations than to those with syntactic ones, as well as in the adjacent STS when sentences with pragmatic violations were compared with normal ones (this study did not include sentences with semantic violations). These studies thus suggest that the left STG may play an important role in processing sentences with pragmatic violations. However, inconsistent findings were observed in a later study that tested the neural correlates of normal sentences and those with syntactic, semantic or pragmatic violations (Kuperberg et al., 2008). The findings revealed greater activity in the left anterior inferior frontal gyrus (IFG) and the bilateral anterior ventromedial temporal cortices (fusiform and parahippocampal gyri) in response to real-world violations than to each of the other three sentence types. The stimuli used in this study were similar to those of the previous study (Kuperberg et al., 2003a), and the word creating the violation was a verb that was not sentence-final. The above studies thus demonstrate increased activity in the left STG when processing pragmatic violations where the target word is at the end of the sentence. In contrast, processing pragmatic violations in which the critical word is a verb or not necessarily sentence-final yields inconsistent results.

Tesink et al. (2011) reported different results. The participants listened to normal sentences (e.g. Dutch trains are *yellow* and blue), sentences containing semantic violations ("Dutch trains are sour and blue"), and sentences with pragmatic world-knowledge violations ("Dutch trains are white and blue"). In this study, the sentences with the pragmatic violations have coherent semantic interpretations but are false. The findings showed greater activity in the left STG and the left IFG for the sentences with the semantic violations than for the normal sentences, but when the sentences with the pragmatic violations were compared to normal ones, the increased activity was seen bilaterally in the IFG but not in the STG area. Direct comparisons between sentences with pragmatic and semantic violations were not reported. Perhaps the use of different type of pragmatic violations may explain the different results.