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Research report

Enhancing lexical ambiguity resolution by brain polarization of the right posterior superior temporal sulcus

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ABSTRACT

Previous studies have reported a hemispheric asymmetry in processing dominant (e.g., paper) and subordinate (e.g., farmer) associations of ambiguous words (pen). Here we applied sham and anodal Transcranial Direct Current Stimulation (tDCS) over Wernicke's area and its right homologue to test whether we can modulate the selective hemispheric expertise in processing lexical ambiguity. Ambiguous prime words were presented followed by target words that could be associated to the dominant or subordinate meaning of the prime in a semantic relatedness task. Anodal stimulation of the right Wernicke's area significantly decreased response time (RTs) to subordinate but not dominant associations compared to sham stimulation. There was also a complementary trend of faster responses to dominant associations following anodal stimulation of Wernicke's area. The results support brain asymmetry in processing lexical ambiguity and show that tDCS can enhance complex language processing even in a sample of highly literate individuals.

1. Introduction

A growing body of evidence suggests that the right hemisphere (RH) plays a role in complex language processing such as ambiguous word comprehension. Lesion (Gardner and Brownell, 1986; Gardner et al., 1983), imaging (Mashal et al., 2007; Rodd et al., 2005; Stringaris et al., 2006) and divided visual field (VF) studies with healthy participants (Burgess and Simpson, 1988; Coney and Evans, 2000; Faust and Kahana, 2002; Faust and Lavidor, 2003) have demonstrated RH involvement in the processing of ambiguous words, at least under some experimental conditions (see Peleg and Eviatar, 2008 for a detailed discussion). Clearly the classical model of hemispheric expertise in which the left hemisphere (LH) processes language exclusively cannot explain the above results, and new models of hemispheric expertise have been suggested (Dien, 2008; Jung-Beeman, 2005; Giora, 2007).

According to the Bilateral Activation, Integration, and Selection (BAIS) model (Jung-Beeman, 2005), underlying this RH involvement in semantic processing are unique processing patterns, termed coarse semantic coding. The coarse patterns are reflected in diffuse activation of distant semantic concepts, followed by their integration and selection. Consistent with the longstanding agreement in the literature regarding the LH significance in semantic processing, the BAIS model also acknowledges the importance of the LH semantic

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processing patterns. The model describes semantic processing in the LH as a fine form of processing (i.e., rapid activation of dominant features which are tightly linked to the input). Since semantic processing in the RH is more diffuse and slower compared to LH semantic processing, the RH's contribution to semantic processing is not clear. However, the ability to directly probe it in healthy patients has significantly developed in the past decade (Jung-Beeman, 2005).

Previous studies of ambiguous word processing typically have employed priming paradigms where the ambiguous word served either as the prime or as the target. The prime-target associations reflected the dominant (e.g., MONEY) or subordinate (RIVER) meanings of the ambiguous word (BANK). Several studies (Burgess and Simpson, 1988; Faust and Kahana, 2002; Faust and Lavidor, 2003) reported priming VF (left, right) × meaning (dominant, subordinate) interactions in which dominant meanings were processed faster than subordinate meanings when presented to the right but not the left VF. If dominant meaning of ambiguous words is defined as a salient meaning (Sereno et al., 1992), and the subordinate meaning is defined as a non-salient stimulus, the graded salience model (Giora, 2007) and the BAIS model (Jung-Beeman, 2005) provide a direct and parsimonious account of the reported interactions. According to these models, the LH is more tuned to process the dominant (i.e., salient) meanings of ambiguous words, while the RH is more likely to process the subordinate (non-salient) meanings of ambiguous words. Here we aim to establish the brain mechanisms supporting the lateralized processing of ambiguous words.

Although many studies have found evidence to support the interaction of hemifield and meaning in ambiguous words as described above, there is still evidence showing that the LH is responsible for most of the ambiguity resolution process. For example, severe deficits in lexical ambiguity processing following left-hemisphere lesions have been reported, regardless of aphasia type or lesion site in several instances (Hagoort, 1993). Meyer and Federmeier (2008) employed event-related potential (ERP) (see also Federmeier and Kutas, 1999) and found that only the LH was sensitive to both the dominant and subordinate meanings, while the RH was sensitive only to the dominant meaning. This discrepancy of priming patterns between the hemispheres attracted the attention of Hasbrooke and Chiarello (1998) who presented target words in a redundant manner to both VFs and found priming for both dominant and subordinate meanings in both fields. Based on their findings, Hasbrooke and Chiarello (1998) suggested a cross-talk mechanism between the hemispheres. According to this mechanism, the meaning- hemisphere interaction should only be observed when the LH resolves the ambiguity of the stimuli by activating the subordinate meaning of a homograph in addition to the dominant meaning. Then and only then are alternative meanings activated in the RH. On the other hand, when the LH does not resolve the ambiguity, no such activation is triggered, and alternative meanings slowly decay in the RH. However, this cross-talk mechanism is not the most parsimonious explanation since it postulates two modes of operation; one which initiates activation in the RH when the LH resolves lexical ambiguity, and the other which does not initiate activation when the LH fails to disambiguate. Nevertheless, the model is a good example of attempts to capture the dynamic hemispheric collaboration in processing language in natural circumstances.

Previous findings therefore reveal somewhat contrasting evidence regarding the processing of dominant and subordinate meanings of ambiguous words in the left and right visual cerebral hemispheres. Since all of the reviewed evidence was collected in behavioural or brain imaging and recording methods, there is no causal evidence linking specific meaning processing to the right or LH. By using Transcranial Magnetic Stimulation (TMS), we were able recently to report first causal evidence that the RH, and in particular the right homologue of Wernicke's area, has a crucial role in processing the subordinate meaning of ambiguous words (Harpaz et al., 2009). Following these pilot results, here we aimed to take advantage of another non-invasive brain stimulation tool, Transcranial Direct Current Stimulation (tDCS), with its unique facilitative (anodal) mode, to explore whether it is possible to improve subject performance in the complex semantic task of resolving semantic ambiguity.

Compared to TMS, tDCS is a more recently developed non-invasive brain stimulation technique that involves the application of small electrical currents to the scalp through two surface electrodes. Weak current flows from the anode, through the cortex, and out through the cathode, as opposed to the phasic electrical responses initiated by the TMS coil. Unlike TMS, which induces currents of sufficient magnitude to stimulate action potentials, the weak electrical currents employed in tDCS are thought to modulate the resting membrane potentials of neurons. tDCS currents are typically applied for up to 20 min, permitting brain stimulation throughout a cognitive paradigm.

Because flow of tDCS current is directional, anodal and cathodal stimulation may have different effects on brain activity. In general, anodal activation causes an enhancement of cortical excitability both during stimulation and for a few minutes thereafter (Nitsche and Paulus, 2000). At least when applied over the motor cortex, cathodal activity appears to have an opposite effect. For example, Nitsche and Paulus (2000) reported an anodal stimulation increased motor excitability, whereas cathodal stimulation produced the opposite effect. The dual-nature of tDCS effects offers a unique set up for the current research. The cathodal mode of the tDCS is suitable for exploring the necessity of a brain region for a specific cognitive function by generating temporary interference of the stimulated region's processing, similar to the typical TMS effects. In addition, and this is a unique property of the tDCS, it is possible to aim to enhance performance by using the anodal mode in a demanding cognitive task such as lexical ambiguity resolution.

Following previous brain imaging studies reporting the involvement of the RH in processing ambiguous words, the target stimulated area was the right homologue of Wernicke's area (Mashal et al., 2007; Rodd et al., 2005; Stringaris et al., 2006). We applied tDCS over Wernicke's area and its right homologue during a semantic decision task in which participants were asked to decide whether an ambiguous word was related or not to a subsequently presented word.

Using the unique properties of tDCS, we aimed to establish whether it is possible to improve complex semantic processing. Whether due to lateralization of language functions or not, the