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Modulating the assessment of semantic speech–gesture relatedness via transcranial direct current stimulation of the left frontal cortex

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ABSTRACT

Background: Co-verbal gestures are crucial for communication. Neuroimaging studies suggest that the left frontal lobe may be especially important for processing metaphoric co-verbal gestures. However, so far, the specific functional relevance of the left frontal lobe in metaphoric (abstract sentence content) co-verbal gesture processing compared to iconic (concrete sentence content) co-verbal gesture processing has not been demonstrated.
Objective: We investigated the functional relevance of the left frontal lobe for processing metaphoric co-verbal gestures using transcranial direct current stimulation (tDCS). We hypothesised a polarisation dependent effect of left frontal tDCS on reaction times and ratings in a speech–gesture semantic relatedness assessment task.
Methods: We applied anodal, cathodal and sham stimulation to the frontal (F3/F4), parietal (CP3/CP4) and frontoparietal (F3/CP4) areas. During stimulation, seventeen subjects were presented with videos of an actor saying concrete or abstract sentences accompanied by related or unrelated iconic or metaphoric gestures and rated to what extent gestures were related to the sentence content.
Results: We found electrode localisation- and polarisation-dependent changes in reaction times and ratings for metaphoric co-verbal gestures compared to iconic gestures. Post-hoc tests revealed a specific polarisation effect for frontoparietal stimulation sites: compared to cathodal stimulation, anodal stimulation of the left frontal lobe decreased reaction times and relatedness assessments for metaphoric conditions only.
Conclusion: Using tDCS, we demonstrated the functional relevance of the left frontal lobe for processing metaphoric co-verbal gestures. Thus, tDCS may possibly constitute an approach to facilitate metaphoric co-verbal gesture-processing in patients with specific deficits.

1. Introduction

Gestures are a fundamental feature of human communication and play important roles for both the recipient and the speaker (e.g. Refs. [1,2]). Co-verbal gestures are a special type of gesture used during verbal communication, and several studies have underlined their importance for communication. For example, it has been shown that co-verbal gestures may facilitate learning [3,4], improve memory performance [3,5,6] and reduce processing demand in face-to-face communication (e.g. Ref. [7]).

Co-verbal gestures can be divided further into iconic and metaphoric gestures, depending on the abstractness of the corresponding speech. Gestures accompanying abstract sentences (e.g. 'the conversation is at a high level' + elevation of hand) are referred to as metaphoric gestures, while gestures that accompany concrete sentences (e.g. 'the house is located on a mountain' + elevation of hand) are called iconic gestures.

1.1. Neural correlates of co-verbal gesture processing

Previous studies investigating the neural correlates of gesture processing have consistently found that speech-processing and gesture-processing networks are largely overlapping [8–12]. Several fMRI studies have highlighted the importance of the (right and particularly left) inferior frontal gyrus (IFG) for both metaphoric [7,13,14] and iconic ([15,16], for a review) co-verbal gestures.

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When comparing metaphoric and iconic co-verbal gestures, however, the left IFG has been found to be especially relevant for processing metaphoric co-speech gestures [14].

While activation of the left IFG is a reliable finding for metaphoric co-speech gesture processing or integration, less is known about the role of the parietal lobe in speech and gesture processing. Some investigations have found activation of the inferior parietal cortex for co-verbal gestures (e.g. Refs. [17,18], for a review). In particular, fMRI data has linked the left inferior parietal lobe to gesture imitation [19], which is in line with lesion research showing defects of this area in patients with apraxia, a condition in which gesture imitation is impaired [20].

1.2. Neural correlates of processing the semantic fit of speech and gestures

In general, the left IFG seems to be involved in semantic processing [21] and is specifically involved in selection [22], retrieval (e.g. Refs. [23–25]) and semantic unification [8,26]. It has been shown that the semantic relation between speech and gestures is relevant for neural processing. Willems et al. demonstrated in an fMRI study that unrelated gestures or words (semantically anomalous in the given context) both led to increased activation in the left IFG [8]. These findings are in line with another study that found bilateral IFG activation for ambiguous words compared to unambiguous words [27]. However, in addition to left IFG activation, the processing of unrelated gestures has also been linked to activation of the right IFG [5,28], and the temporal and parietal cortices may even play a role [29].

1.3. tDCS in gesture processing

Evidence from neuroimaging is merely correlational: on its own, it does not allow the direct linking of brain structures to specific functions. A non-invasive brain stimulation method such as tDCS may serve as an excellent tool for exploring the functional relevance of the findings outlined above.

The first study that probed a possible modulation of gestural–verbal semantic integration via tDCS used short video clips showing a masked actor performing either a symbolic or a pantomimic gesture; this was followed by a written word that either accurately described the gesture/pantomime or was unrelated to it [30]. Subjects were asked to judge whether or not the gesture/pantomime was related to the clip. Anodal stimulation over the right IFG coupled with cathodal stimulation over the left IFG generated faster responses to symbolic gestures than inverse or sham stimulation.

However, a 2013 study investigating tDCS effects on performance in a gesture-matching task found improved performance after the stimulation of an entirely different brain region, namely, the left parietal cortex [31]. Pairs of pictures showing a female actress performing meaningless hand gestures and displaying either identical or slightly different gestures were presented and subjects were asked to judge whether or not the gestures matched. Faster reaction times were found for anodal tDCS over the supramarginal gyrus and angular gyrus of the inferior parietal lobe. Similarly, Bolognini et al. found that apraxia could be improved using tDCS of the left posterior parietal cortex, highlighting the importance of this region for gesture planning [32].

1.4. Current study

In sum, there is some evidence from brain imaging suggesting IFG and, possibly, parietal involvement in the assessment of speech and gesture relatedness. Initial tDCS evidence for gesture processing seems to support the importance of these brain regions. However, the influence of tDCS on the processing of co-verbal gestures has not yet been investigated and the relative contribution of frontal and parietal areas to speech–gesture relatedness assessment remains unknown.

In this study, we aimed to discern the electrode localisation- and polarisation-dependent effects of tDCS on the assessment of speech–gesture relatedness for metaphoric and iconic co-verbal gestures that were either related or unrelated to speech content. Based on earlier fMRI data, we hypothesised a specific polarisation-dependent effect of left frontal tDCS on ratings and reaction times for metaphoric gestures. In particular, we predicted faster and more critical assessment during left frontal anodal stimulation, reflected in reduced reaction times and ratings.

To disentangle the effects of electrode localisation and polarisation completely, we included two frontal, two parietal and two frontoparietal conditions as well as a sham condition in our design. In this way, we hoped to gain maximum insight into the relative contribution of each stimulated area to co-verbal gesture processing.

2. Methods and material

2.1. Participants

Seventeen healthy, right-handed native German speakers were recruited via posters placed in public buildings in Marburg, Germany (eleven male, six female, mean age = 36.41, SD = 12.96, range = 23–59). All participants fulfilled the following inclusion criteria: right-handedness, history free of mental or neurologic illness and alcohol or drug abuse, normal or corrected-to-normal vision, no hearing deficits, no electric implants. All subjects gave written informed consent prior to participation and received €150 as an expense allowance for participating in all seven sessions. The study was approved by the local ethics committee.

2.2. Transcranial direct current stimulation

In this study, we used a DC-Stimulator from neuroConn GmbH (Ilmenau). Frontal electrodes were positioned at F3/F4, while parietal electrodes were positioned at C3-P3/C4-P4 (between C3 and P3/between C4 and P4), according to the 10–20 EEG system. A current of 1.5 mA was applied to the head using saline-soaked sponges (0.9% NaCl, to minimise side effects, see Refs. [33,34], 5 cm × 7 cm) placed on rubber electrodes, resulting in a current density of 0.043 mA/cm^2. The duration of the stimulation was 10 min plus 10 s fade in/fade out. These parameters are in compliance with tDCS safety guidelines [35–37]. Sessions were performed at least 20 h apart to ensure that the tDCS effects had completely faded away by the beginning of each new session. Sham stimulation was performed using the sinus (HW) mode for a duration of 30 s, ensuring that subjects would feel the itching sometimes associated with the beginning of stimulation and would therefore be unable to distinguish between sham and real stimulation [38].

2.3. Experiment design

We applied anodal, cathodal and sham stimulation to the left and right frontal (F3/F4) and parietal (CP3/CP4) areas (see Fig. 1). Each subject took part in seven independent tDCS sessions and underwent seven different stimulation conditions, one on each day (L = left; R = right; F = frontal; P = parietal; C = cathode; A = anode): 1) two frontal conditions with inverse polarisation – LFC-RFA and LFA-RFC; 2) two frontoparietal conditions with inverse