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Transcranial Direct Current Stimulation Effects on Semantic Processing in Healthy Individuals

Marilyne Joyal [a,b,c], Shirley Fecteau [a,b,c,*]

[a] Centre interdisciplinaire de recherche en réadaptation et en intégration sociale, 525, Boul. Wilfrid-Hamel, Bureau H-1312, Québec (QC), Canada, G1M 2S8
[b] Centre de recherche de l'Institut universitaire en santé mentale de Québec, 2601, de la Canardière, Québec (QC), Canada, G1J 2G3
[c] Faculté de médecine, Université Laval, 1050, avenue de la Médecine, Québec (QC), Canada, G1V 0A6

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ABSTRACT

Background: Semantic processing allows us to use conceptual knowledge about the world. It has been associated with a large distributed neural network that includes the frontal, temporal and parietal cortices. Recent studies using transcranial direct current stimulation (tDCS) also contributed at investigating semantic processing.
Objective/hypotheses: The goal of this article was to review studies investigating semantic processing in healthy individuals with tDCS and discuss findings from these studies in line with neuroimaging results. Based on functional magnetic resonance imaging studies assessing semantic processing, we predicted that tDCS applied over the inferior frontal gyrus, middle temporal gyrus, and posterior parietal cortex will impact semantic processing.
Methods: We conducted a search on Pubmed and selected 27 articles in which tDCS was used to modulate semantic processing in healthy subjects. We analysed each article according to these criteria: demographic information, experimental outcomes assessing semantic processing, study design, and effects of tDCS on semantic processes.
Results: From the 27 reviewed studies, 8 found main effects of stimulation. In addition to these 8 studies, 17 studies reported an interaction between stimulus types and stimulation conditions (e.g. incoherent functional, but not instrumental, actions were processed faster when anodal tDCS was applied over the posterior parietal cortex as compared to sham tDCS). Results suggest that regions in the frontal, temporal, and parietal cortices are involved in semantic processing.
Conclusions: tDCS can modulate some aspects of semantic processing and provide information on the functional roles of brain regions involved in this cognitive process.

Introduction

Semantic processing is a fundamental cognitive function collecting, retrieving and storing information about the world. It allows us to understand and express the meaning of words, objects, sounds, facial expressions, odours, and events, as well as to act accordingly in various social interactions and daily life activities [1]. Semantic processing has been mainly studied with behavioural tasks using visual stimuli (e.g. to name pictures or to determine whether two written words are semantically related).

Semantic processing has been associated with a large distributed neural network that involves the frontal, temporal and parietal cortices. A meta-analysis that comprises 120 functional magnetic resonance imaging (fMRI) studies investigating the neural substrates of semantic processing reported a left-lateralized network that includes the inferior frontal gyrus (IFG), dorsomedial prefrontal cortex, ventromedial prefrontal cortex, middle temporal gyrus (MTG), the posterior parietal cortex (PPC), fusiform and parahippocampal gyri, and the posterior cingulate gyrus [2].

Transcranial direct current stimulation (tDCS) can also provide information on brain regions and networks involved in cognitive processes [3]. This noninvasive brain stimulation method can modulate brain activity within a region such as under the surface electrodes [4] and within networks. This neural modulation may thus be local and distal to the site of stimulation [5,6] and subsequently impact related cognitive functions.

In this article, we review studies investigating semantic processing in healthy individuals with tDCS. We predicted that tDCS

* Corresponding author. Tel.: +1 418 529 9141; fax: +1 418 529 3548.
E-mail address: shirley.fecteau@fmed.ulaval.ca (S. Fecteau).

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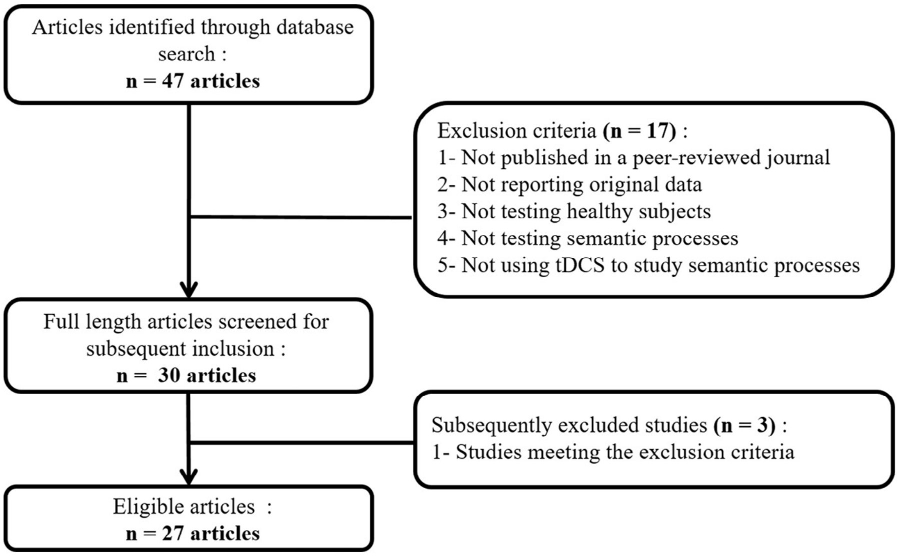

Figure 1. Flowchart of the study selection process.

applied over the IFG, MTG, and PPC will impact semantic processing. These hypotheses were based on fMRI data indicating that these regions are involved in semantic processing [2] and can be non-invasively targeted with tDCS.

Methods

In order to assess whether tDCS can modulate semantic processing in healthy subjects and if so, which brain regions were targeted with tDCS, we conducted a systematic database search in PubMed. In the first phase of study selection, we used keywords "semantic" AND "tDCS" OR "transcranial direct current stimulation" with no limitation of publication date. This search resulted in a total of 47 articles published between April 2008 and March 2016. In the second phase of study selection, we excluded articles 1) not published in a peer-reviewed journal, 2) not testing healthy subjects, 3) not assessing semantic processes, and 4) not using tDCS to study semantic processing. This selection resulted in 27 articles (Fig. 1). We collected demographic and experimental characteristics from these 27 articles including, when available: 1) demographic information, 2) study design, 3) experimental outcomes assessing semantic processing, and 4) effects of tDCS on semantic processes.

Results

Demographic information

The 27 reviewed articles included a total of 838 healthy subjects whose semantic processes were studied with tDCS (Tables 1 and 2). This sample was composed of 56% of women (this excludes subjects from one study [13] as this information was not available) with a mean age of 28 years old. Of note, mean age was not available in two studies, which reported ranges: 19 to 22 years old [9] and 22 to 60 years old [14]. Also, two studies included elderly adults [19,23]. All subjects were right-handed (but this information was not available in two studies [9,24]).

Experimental outcomes assessing semantic processing

The 27 reviewed articles administered various tasks to assess semantic processing including naming, semantic fluency, semantic judgement, semantic priming and overt word generation tasks. Most experimental outcomes were accuracy rate (or error rate), number of correctly generated words, and response time (see Tables 1 and 2 for all experimental tasks and outcomes). In addition to these behavioural outcomes, 9 studies assessed changes in neural substrates using EEG [18,19,23,24,27], fMRI [10,11,30], and functional near-infrared spectroscopy [16].

Study design

From the 27 reviewed articles, 18 used a crossover design, 5 a parallel design and 4 a mixed design (within-subject and between-subject measures). Eleven studies used single blind design and 6 used double blind design. Stimulation intensity ranged from 1 to 2 mA and duration from 6 to 37 minutes. Electrode sizes ranged from 3×3 cm to 10×10 cm, with most studies using 5×7 cm electrodes, and seven studies using larger reference electrode than the active one. Finally, two studies used a ring electrode montage (i.e., four cathode electrodes placed around a single anode electrode [28,33]). Electrode locations were mainly based on the International 10–20 system. Three studies used anatomical MRI with a neuronavigation system [8,13,14]. One study, targeting the primary motor cortex, placed the tDCS electrodes over the area of the primary motor cortex that elicited a hand twitch using single pulse transcranial magnetic stimulation [29].

Effects of tDCS on semantic processes

tDCS effects on semantic processing varied across studies (Tables 1 and 2). Semantic processes were improved (e.g., decreased response time [15]) or disrupted (e.g., increased response time [8]). Semantic processes were also modulated without being improved or disrupted. For instance, in a categorization task, subjects selected more stimuli weakly associated with the target category when they received anodal tDCS over the left IFG with cathodal tDCS over the right mastoid as compared to the opposite electrode montage or without stimulation [9].

Eight out of the 27 studies found a main effect of stimulation. Seventeen other studies found an interaction between stimulation conditions and stimulus types. Stimuli varied on various features of semantic processing, such as congruency, category and degree