# Facilitated Lexical Ambiguity Processing by Transcranial Direct Current Stimulation over the Left Inferior Frontal Cortex

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## Abstract

■ Previous studies suggest that the left inferior frontal cortex is involved in the resolution of lexical ambiguities for language comprehension. In this study, we hypothesized that processing of lexical ambiguities is improved when the excitability of the left inferior frontal cortex is enhanced. To test the hypothesis, we conducted an experiment with transcranial direct current stimulation (tDCS). We investigated the effect of anodal tDCS over the left inferior frontal cortex on behavioral indexes for semantic judgment on lexically ambiguous and unambiguous words within a context. Supporting the hypothesis, the RT was shorter in the anodal tDCS session than in the sham session for ambiguous words. The results suggest that controlled semantic retrieval and contextual selection were facilitated by anodal tDCS over the left inferior frontal cortex. ■

## INTRODUCTION

Many words have the same pronunciation and spelling but semantically unrelated meanings (e.g., "bank"). For such lexical ambiguity, we can select one appropriate meaning from among multiple alternatives by using context (e.g., "I withdrew some money at the bank"/"I strolled along the bank of the river"). Flexible processing of ambiguous words is crucial for smooth language comprehension.

In fMRI studies, the bilateral cortical areas showed stronger activity for ambiguous words than unambiguous words (Bilenko, Grindrod, Myers, & Blumstein, 2009; Mason & Just, 2007; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007; Rodd, Davis, & Johnsrude, 2005; Chan et al., 2004). Regarding lexical ambiguity resolution, lesion and behavioral studies have reported distinct functioning of the two cerebral hemispheres: the left hemisphere is involved in contextual integration and selection of a contextually appropriate meaning, whereas the right hemisphere is involved in maintenance of alternative meanings (Faust, 2003; Grindrod & Baum, 2003; Copland, Chenery, & Murdoch, 2002; Faust & Chiarello, 1998). In the left hemisphere, the inferior frontal cortex (IFC) especially seems to be important for selecting contextually appropriate meanings of ambiguous words. Broca's aphasics have delayed processing of contextual selection of meanings for ambiguous words (Swaab, Brown, & Hagoort, 2003; Hagoort, 1993).

Our previous study also supported the view that the left IFC plays an important role in the resolution of lexical ambiguities (Ihara, Hayakawa, Wei, Munetsuna, & Fujimaki, 2007). By using magnetoencephalography (MEG), we investigated the spatiotemporal characteristics of neural activities for lexical access and selection of contextually appropriate meanings for ambiguous words. The results suggested that multiple meanings are initially accessed with no influence from preceding contextual information, and the ambiguity is subsequently resolved by controlled semantic retrieval and contextual selection in the left anterior (BA 47) and posterior IFC (BA 45/BA 9).

On the basis of this idea, if the excitability of the left IFC can be increased, the behavioral performance of lexical ambiguity processing should improve. In this study, we conducted an experiment using transcranial direct current stimulation (tDCS) as a noninvasive technique to modulate cortical excitability (Nitsche & Paulus, 2000; Priori, Berardelli, Rona, Accornero, & Manfredi, 1998). During tDCS, weak direct currents are delivered to the cortex via two electrodes placed on the scalp. A lot of studies have shown there are polarity-dependent modulations in the response of the motor output system: Anodal stimulation delivered over the motor cortex increases cortical excitability, whereas cathodal stimulation decreases it (Nitsche et al., 2008). The cellular and molecular

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mechanisms underlying the neuromodulation by tDCS have gradually been revealed. Unlike TMS, tDCS does not elicit action potentials. tDCS modifies spontaneous neuronal excitability and activity through tonic de- or hyperpolarization of the resting membrane potential and induces long-term potentiation dependent on the NMDA (*N*-methyl-D-aspartate) receptor (Liebetanz, Nitsche, Tergau, & Paulus, 2002). The coupling of direct current stimulation with repetitive low-frequency synaptic activation enhances brain-derived neurotrophic factor secretion and activation of the receptor TrkB (tropomyosin receptor kinase), which are required for synaptic plasticity (Fritsch et al., 2010).

There is growing evidence that anodal tDCS facilitates not only motor functions but also cognitive functions, such as working memory (Boggio et al., 2006; Fregni et al., 2005), planning (Dockery, Hueckel-Weng, Birbaumer, & Plewnia, 2009), and learning (Kincses, Antal, Nitsche, Bartfai, & Paulus, 2004). The numbers are small, but there are studies that have investigated the effect of tDCS on language functions. The studies on healthy participants showed that anodal tDCS over Broca's area facilitated verbal fluency (Cattaneo, Pisoni, & Papagno, 2011; Iyer et al., 2005), grammar learning (de Vries et al., 2010), and picture naming (Fertonani, Rosini, Cotelli, Rossini, & Miniussi, 2010) and that anodal tDCS over Wernicke's area also facilitated verbal learning (Flöel, Rosser, Michka, Knecht, & Breitenstein, 2008) and picture naming (Sparing, Dafotakis, Meister, Thirugnanasambandam, & Fink, 2008). Furthermore, it has been shown that anodal tDCS over these language areas is involved in recovery of language functions in aphasic participants (Fiori et al., 2011; Fridriksson, Richardson, Baker, & Rorden, 2011; Marangolo et al., 2011). However, little has been reported on the effect of tDCS on language comprehension (You, Kim, Chun, Jung, & Park, 2011).

In this study, we hypothesized that anodal tDCS over the left IFC facilitates processing of lexically ambiguous words. To test the hypothesis, we investigated the effect of tDCS on behavioral indexes, that is, RT and accuracy rate, obtained when the participants performed a semantic judgment task with lexically ambiguous and unambiguous words. The stimuli and conditions were the same as those used in our previous study with the semantic priming paradigm (Ihara et al., 2007). The stimuli were Japanese word pairs in which the targets were either ambiguous or unambiguous words, and these were either semantically related or unrelated to the primes: that is, there were related ambiguous, unrelated ambiguous, related unambiguous, and unrelated unambiguous conditions. The participants were required to judge whether the target words were semantically related or unrelated to the prime words. When the target was an ambiguous word and one of the meanings was semantically related to the prime, the participant could select one contextually appropriate meaning from among the multiple alternatives; that is, the lexical ambiguity was resolved. When the target was an ambiguous word and no meanings were semantically related to the prime, the participant could not select one meaning for the target. On the other hand, when the target was an unambiguous word, the meaning could be determined independent of the relation with the prime. We compared the behavioral indexes of anodal sessions (15-min anodal tDCS over the left IFC) and sham sessions (30-sec tDCS).

## METHODS

### Participants

Fourteen native speakers of Japanese participated in the experiment (seven men and seven women, 22–60 years old). All participants were right-handed (mean laterality quotient = +97.7), as confirmed by the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. They had no history of neurological or psychiatric disease. The study was approved in advance by the Ethics Committee for Human and Animal Research of the National Institute of Information and Communications Technology, Japan. Informed consent to participate in the study was obtained from all participants.

### Semantic Judgment Task

The stimuli and conditions have been described in detail in our paper (Ihara et al., 2007). The stimuli were Japanese word pairs. Japanese has two different writing systems, one consisting of syllabograms (kana) and the other consisting of morphograms (kanji). Each kana represents one mora, which is a unit of rhythm in spoken Japanese usually consisting of a single vowel or a consonant and a vowel. Each kanji has semantic values with one or more morae. The prime words were written with two morphograms (kanji) and pronounced with either three or four morae. The target words were ambiguous or unambiguous words written with three to five syllabograms (kana) and pronounced with either three or four morae. The unambiguous target words had only one pronunciation and one meaning. For example, "ほくい," pronounced /hokui/, only means "north latitude." The ambiguous target words were homonyms that had one pronunciation but multiple unrelated meanings with high familiarity values (>5 on a 7-grade scale) in the Lexical Properties of Japanese database (Amano & Kondo, 1999). For example, "でんき," pronounced /denki/, can mean "biography" or "electricity." According to the type of target word, four conditions were set up: ambiguous words with meanings related to the prime word (RA), ambiguous words with meanings unrelated to the prime word (UA), unambiguous words related to the prime word (RU), and unambiguous words unrelated to the prime word (UU; Table 1).

For each condition, 90 word pairs were chosen from the stimuli used in our MEG study (Ihara et al., 2007) and divided into three sets (A, B, and C). The results of

**Table 1.** Experimental Conditions and Stimuli

| | | | *Example* | |
|---|---|---|---|---|
| | | | *Prime* | *Target* |
| *Condition* | *Relation* | *Ambiguity* | *"English Translation"* | |
| RA | related | ambiguous | 小説 | でんき |
| | | | "novel" | "biography," "electricity," etc. |
| UA | unrelated | ambiguous | 花粉 | きかい |
| | | | "pollen" | "chance," "machine," etc. |
| RU | related | unambiguous | 地球 | ほくい |
| | | | "earth" | "north latitude" |
| UU | unrelated | unambiguous | 外壁 | ねごと |
| | | | "wall" | "sleep talking" |

a Kruskal–Wallis test showed that the target words had no differences in the number of meanings for the ambiguous words, the number of senses per meaning, the number of characters, the number of morae, and imagenability values, as indicated in the Lexical Properties of Japanese database (Sakuma et al., 2005), across sets and conditions (Table 2). In the previous study (Ihara et al., 2007), the relatedness of words in a pair was evaluated by 31 volunteers on a 5-grade scale ranging from 1 (*weakly related*) to 5 (*strongly related*). The results of the Kruskal–Wallis test

**Table 2.** Target Word Properties

| | | *Condition* | | | |
|---|---|---|---|---|---|
| *Properties* | *Set* | *RA* | *UA* | *RU* | *UU* |
| Number of meanings | A | 2.2 ± 0.6 | 2.1 ± 0.3 | 1.0 ± 0.0[a] | 1.0 ± 0.0[a] |
| | B | 2.2 ± 0.4 | 2.1 ± 0.3 | 1.0 ± 0.0[a] | 1.0 ± 0.0[a] |
| | C | 2.1 ± 0.4 | 2.1 ± 0.3 | 1.0 ± 0.0[a] | 1.0 ± 0.0[a] |
| Number of senses per meaning | A | 1.6 ± 0.5 | 1.5 ± 0.5 | 1.5 ± 0.7 | 1.3 ± 0.6 |
| | B | 1.4 ± 0.5 | 1.3 ± 0.4 | 1.4 ± 0.7 | 1.2 ± 0.4 |
| | C | 1.4 ± 0.5 | 1.4 ± 0.5 | 1.5 ± 0.7 | 1.3 ± 0.6 |
| Number of characters | A | 4.1 ± 0.7 | 4.0 ± 0.6 | 4.0 ± 0.4 | 4.1 ± 0.5 |
| | B | 3.8 ± 0.7 | 3.9 ± 0.8 | 3.9 ± 0.5 | 4.0 ± 0.6 |
| | C | 4.2 ± 0.7 | 3.8 ± 0.7 | 4.1 ± 0.6 | 4.0 ± 0.7 |
| Number of morae | A | 3.6 ± 0.6 | 3.8 ± 0.4 | 3.8 ± 0.4 | 3.8 ± 0.4 |
| | B | 3.5 ± 0.6 | 3.5 ± 0.6 | 3.7 ± 0.5 | 3.7 ± 0.5 |
| | C | 3.7 ± 0.5 | 3.6 ± 0.5 | 3.8 ± 0.4 | 3.6 ± 0.5 |
| Imageability values | A | 4.2 ± 0.5 | 4.1 ± 0.5 | 4.3 ± 0.5 | 4.4 ± 0.6 |
| | B | 4.2 ± 0.5 | 4.1 ± 0.5 | 4.4 ± 0.7 | 4.4 ± 0.5 |
| | C | 4.4 ± 0.5 | 4.3 ± 0.6 | 4.3 ± 0.5 | 4.4 ± 0.5 |
| Relatedness | A | 4.6 ± 0.2 | 1.4 ± 0.1 | 4.6 ± 0.2 | 1.4 ± 0.1 |
| | B | 4.6 ± 0.2 | 1.4 ± 0.1 | 4.6 ± 0.2 | 1.4 ± 0.2 |
| | C | 4.6 ± 0.3 | 1.4 ± 0.1 | 4.6 ± 0.2 | 1.4 ± 0.2 |

Mean ± *SD*.

[a] The unambiguous words had only one meaning.

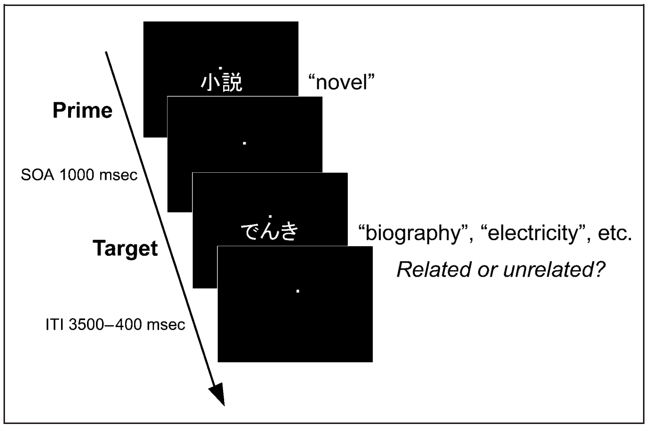

**Figure 1.** Schematic representation of the stimulus sequence. The prime and target words were presented with a SOA of 1000 msec. Participants were instructed to judge whether the target words were semantically related or unrelated to the prime words and press one of the two keys with the right finger as quickly and accurately as possible. The intertribal interval between the offset of the target and the onset of the next prime was randomly set at 3500–4000 msec.

showed the relatedness has no difference between RA and RU, between UA and UU, and across the three sets. For each participant, two sets of three were chosen, one of which was used in the tDCS session and the other in the sham session. The sets were well-randomized across participants.

Figure 1 shows an example of one epoch. The prime and target words were visually presented with a SOA of 1000 msec. The stimulus duration was 300 msec for each word. The prime word in the next trial was randomly presented 3500–4000 msec after the onset of the target word. Each word pair in the four conditions was delivered in a pseudorandom order. The prime and target words were projected on a screen centrally in front of the participant. The height of each word subtended a visual angle of 0.8°, and the length of each word subtended a visual angle of 4° or less. Each word was displayed 0.1° below the fixation point. The luminance of the stimuli and their background were respectively 120 and 2 cd/m$^2$.

Participants were instructed to gaze at the fixation point and to judge whether the target words were semantically related or unrelated to the prime words and press one of the two keys with the right finger as quickly and accurately as possible. Seven participants were asked to press a key with the index finger for related pairs and another key with the middle finger for unrelated pairs; six participants were asked to press a key with the middle finger for related pairs and another key with the index finger for unrelated pairs. The semantic judgment task lasted approximately 10 min.

## Simple Reaction Task

A simple reaction task was performed to verify that the effect of tDCS in the semantic judgment task was not just because of facilitation or inhibition of attentional and/or motor function. The cues for pressing a key, square shapes with horizontal and vertical visual angles of 0.8°, were centrally projected on a screen in front of the participant with an SOA of 1000–8000 msec. Each cue was displayed 0.1° below the fixation point. The stimulus duration was 300 msec for each cue. The luminance of the cues and their background were respectively 120 and 2 cd/m$^2$. Participants were instructed to gaze at the fixation point and to press a key with the right finger as soon as the cue was presented.

## Transcranial Direct Current Stimulation

tDCS was delivered by a battery-driven constant DC current stimulator (neuro-Conn GmbH, Ilmenau, Germany) through a pair of saline-soaked sponge electrodes (5 × 7 cm). The electrode to which the terminology "anodal" refers was positioned over the left IFC, in which the activations were observed in our previous MEG study (Ihara et al., 2007), by means of the following navigation method. In the previous study, the mean dipole locations in the left IFC across the participants were shown in Talairach coordinates (Talairach & Tournoux, 1998): the left anterior IFC ($-45$, 28, $-16$) and the left posterior IFC ($-52$, 24, 23). In this study, we identified the two locations by using the Brainsight 2 neuronavigation system (Rogue Research, Montreal, Quebec, Canada) and an anatomical MRI of each participant. The neuronavigation system registers the MRI data in the Talairach coordinate space, and it allows us to use Talairach coordinates to define the stimulus sites. It also simultaneously visualizes the location of the pointer on a 3-D MRI. We made two

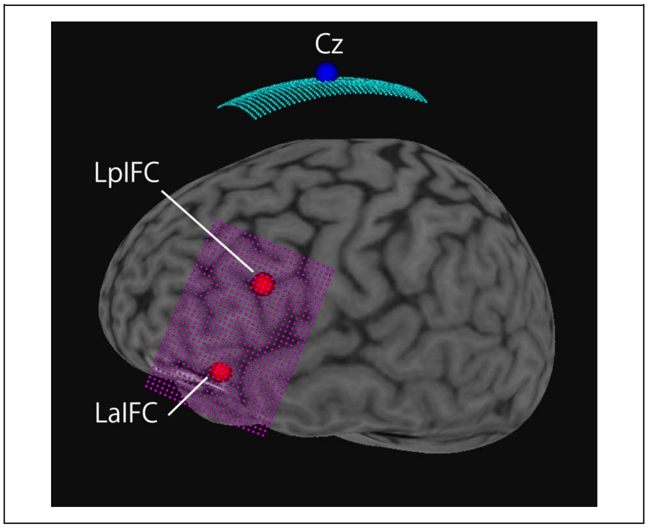

**Figure 2.** Target regions for cortical stimulation in a participant. Anodal current stimulation (magenta) was applied to a region corresponding to the left anterior inferior cortex (LaIFC) and the left posterior inferior cortex (LpIFC) by means of a neuronavigation system loaded with an anatomical MRI of each participant. The center of electrode was placed over the median of the two points. The reference (cathode) electrode (cyan) was centered over Cz of the International 10–20 system for EEG electrode placement.

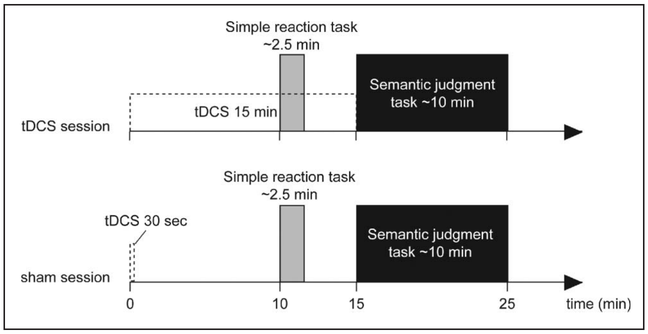

**Figure 3.** Study design. Participants took part in both tDCS and sham sessions. An anodal stimulation (1.5 mA) was delivered for 15 min in the tDCS session and for 30 sec in the sham session. In both sessions, the simple reaction task started 10 min after the tDCS onset, and the semantic judgment task started 15 min after the tDCS onset.

marks for the left anterior IFC and posterior IFC on the scalp of the participant by positioning the pointer at the two sites on the 3-D MRI. Accordingly, the center of electrode was placed over the median of the two marks (Figure 2). The MRI was performed with a 1.5-T (Magnetom Vision, Siemens A.G., Erlangen, Germany; Signa EXCITE, GE, Chalfont St. Giles, UK) or 3.0-T MRI system (Magnetom Trio, Siemens A.G.). Whole brain T1-weighted coronal, axial, and sagittal images with a contiguous 1.0-mm slice thickness were taken. The reference (cathode) electrode was centered over Cz of the International 10–20 system for EEG electrode placement (Sparing et al., 2008).

The tDCS and sham sessions for each participant were as follows. A 1.5-mA anodal stimulation (0.043 mA/cm$^2$) was delivered for 15 min in the tDCS session (Figure 3). The current intensity in the sham session was the same as in the tDCS session, but the stimulator was turned off after 30 sec in the sham session, as was done in the previous tDCS studies (Flöel et al., 2008; Sparing et al., 2008). In both sessions, the simple reaction task started 10 min after the tDCS onset; this was done because a lot of studies reported that motor function was influenced by tDCS with a lower current density (0.029 mA/cm$^2$) for less than 10 min (Nitsche et al., 2008). The semantic judgment task started 15 min after the tDCS onset. Instructions to the participants were identical for both sessions. The order of the sessions was randomized across participants: Six subjects participated the tDCS session, and the remaining seven participated in the sham session first. The interval between sessions was more than 24 hr.

At the end of each session, the participants rated their subjective assessment of the tDCS sensation on a 6-grade scale: 0 = *no sensation*, 1 = *very weak*, 2 = *weak*, 3 = *middle*, 4 = *strong*, and 5 = *very strong*. The participants also evaluated their subjective mood and wakefulness during the semantic judgment task in each session on a 5-grade scale ranging from 1 (*very bad*/*very sleepy*) to 5 (*very good*/*very awake*). In addition, after the two sessions, the participants were asked to identify in which session they had received tDCS for 15 min.

## Analysis

The RT and accuracy rate for the semantic judgment task were averaged selectively for each condition in each session. Epochs in which the participants answered incorrectly were excluded from the RT averages. Differences in RT and accuracy rate across the sessions and conditions were assessed by repeated-measures ANOVA with three within-subject factors: Session (tDCS and sham), Relation (related and unrelated), and Ambiguity (ambiguous and unambiguous). For significant results ($p < .05$), paired $t$ tests were performed. The RT for the simple reaction task was also averaged selectively in each session. Differences

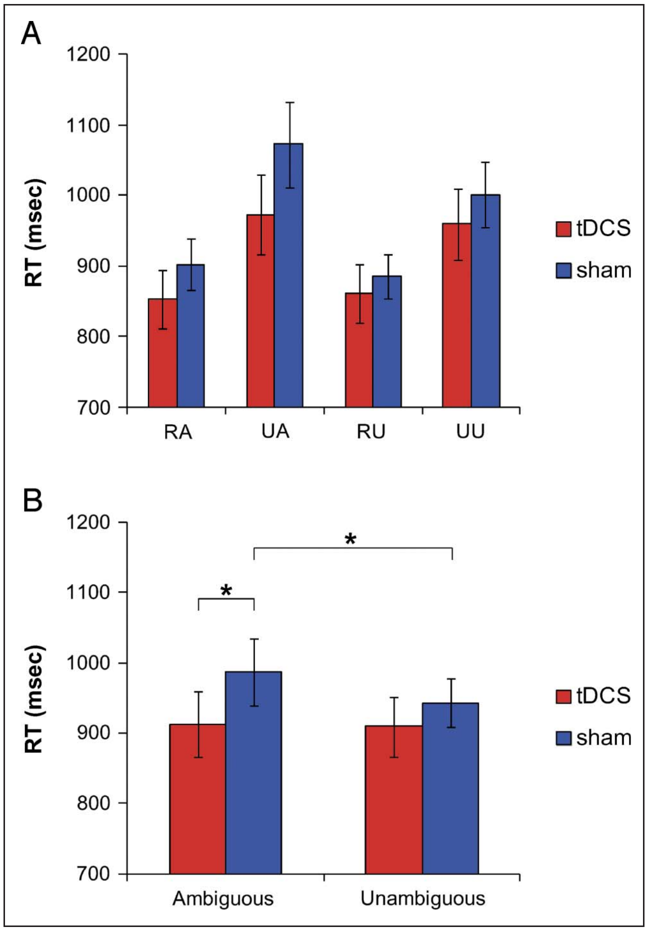

**Figure 4.** Mean RT in the semantic judgment task. (A) Three-way repeated-measures ANOVA (Session × Relation × Ambiguity) for the RT revealed a significant interaction between Session and Ambiguity ($p < .05$) and a main effect of Relation ($p < .005$). The red bars show the tDCS session, and the blue bars show the sham session. The error bars show the *SE*. (B) Interaction between Session and Ambiguity. The RT for the ambiguous condition was shorter in the tDCS session than in the sham session, whereas there was no difference for the unambiguous condition. The RT was longer for the ambiguous condition than for the unambiguous condition in the sham session, whereas there was no difference in the tDCS session. The red and blue bars for ambiguous condition show mean RTs between RA and UA in the tDCS and sham session, respectively. The red and blue bars for unambiguous condition show mean RTs between RU and UU in the tDCS and sham session, respectively. The error bars show the *SE*. *$p < .05$.

in RT between the sessions were assessed by one-way repeated-measures ANOVA (tDCS and sham). Differences in the subjective assessments of the stimulus's sensation, mood, and wakefulness were assessed with a Wilcoxon signed-rank test.

## RESULTS

tDCS showed no effect on the accuracy rate. A three-way repeated-measures ANOVA (Session × Relation × Ambiguity) for the accuracy rate showed only a significant main effect of Relation, $F(1, 13) = 16.31$, $p < .005$; the accuracy rate was lower for the related condition (mean ± *SE*: 94 ± 1% for RA and 95 ± 1% for RU in the tDCS session; 94 ± 2% for RA and 97 ± 1% for RU in the sham session) than for the unrelated condition (98 ± 1% for UA and 97 ± 1% for UU in the tDCS session; 98 ± 1% for UA and 99 ± 1% for UU in the sham session).

A three-way repeated-measures ANOVA for the RT revealed a significant interaction between Session and Ambiguity, $F(1, 13) = 5.70$, $p < .05$ (Figure 4A); the RT for the ambiguous condition was shorter in the tDCS session (mean ± *SE*: 852 ± 42 msec for RA; 973 ± 57 msec for UA) than in the sham session (901 ± 37 msec for RA; 1072 ± 62 msec for UA; $p < .05$), whereas there was no significant difference for the unambiguous condition between tDCS (860 ± 41 msec for RU; 959 ± 50 msec for UU) and sham sessions (885 ± 32 msec for RU; 1001 ± 47 msec for UU; Figure 4B). Furthermore, in the sham session, the RT was longer for the ambiguous condition than for the unambiguous condition ($p < .05$), whereas no effect was found in the tDCS session (Figure 4B). The ANOVA for the RT also showed a significant main effect of Relation, $F(1, 13) = 16.40$, $p < .005$, which showed that the RT was shorter for the related condition than for the unrelated condition. A one-way repeated-measures ANOVA showed no difference in RT between the tDCS (311 ± 7 msec) and sham sessions (322 ± 10 msec) for the simple reaction task (Figure 5). The subjective assessments of the stimulus sensation, mood, and wakefulness revealed no significant differences between the tDCS and sham sessions (Table 3).

**Table 3.** Subjective Assessment of Stimulus Sensation, Mood, and Wakefulness

| | *tDCS* | *Sham* | *Wilcoxon Signed-rank Test* |
|---|---|---|---|
| Stimulus sensation | 1.8 ± 0.3 | 1.7 ± 0.3 | *ns* |
| Mood | 3.2 ± 0.2 | 3.0 ± 0.1 | *ns* |
| Wakefulness | 3.3 ± 0.3 | 3.2 ± 0.2 | *ns* |

Mean ± *SE*. *ns* = not significant.

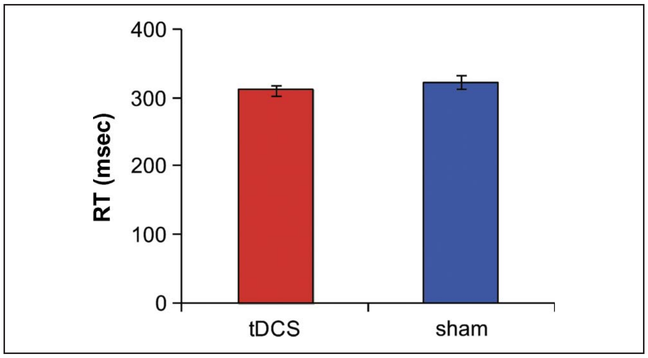

**Figure 5.** Mean RT in the simple reaction task. There was no difference in RT between the tDCS and sham sessions. The error bars show the *SE*.

## DISCUSSION

Our results support the hypothesis that anodal tDCS over the left IFC facilitates processing of lexically ambiguous words. For the semantic judgment task, the RT was shorter in the tDCS session than in the sham session for ambiguous conditions (RA and UA), but not for the unambiguous conditions (RU and UU). For the simple reaction task, there was no difference in RT between the tDCS and sham sessions. The results show the shortened RT in the ambiguous conditions was not caused just by facilitation of attentional and/or motor function.

In the sham session, the RT was longer for the ambiguous conditions (RA and UA) than for the unambiguous conditions (RU and UU), which was a reproducible result of our previous study (Ihara et al., 2007). Many studies reported that the lexical decisions were faster on ambiguous words than unambiguous words (Azuma & VanOrden, 1997; Borowsky & Masson, 1996; Hino & Lupker, 1996), the so-called ambiguity advantage. In describing the ambiguity advantage, Klein and Murphy (2001) and Rodd, Gaskell, and Marslen-Wilson (2002) noted that most research failed to distinguish between two types of ambiguity: homonymy and polysemy. Homonymy means multiple unrelated meanings, whereas polysemy means multiple related senses. The ambiguity advantage could have been caused by uncontrolled polysemy, but not by homonymy. Rodd and colleagues showed that once polysemy was controlled for, homonymy actually slowed access, whereas polysemy quickened it. A MEG study also demonstrated that words with multiple senses elicited earlier RTs and M350 peak latencies than words with few senses, wherein words with more than one meaning elicited later RTs and M350 peak latencies than words with a single meaning (Beretta, Fiorentino, & Poeppel, 2005). In this study, we controlled the number of senses per meaning (Table 2), and so the differences caused by ambiguities in our experiment were attributed to homonymy, but not polysemy. Therefore, the result that the RT was longer for the ambiguous words than for the unambiguous words in the sham session was consistent with the previous studies.

The delayed RT to ambiguous words was not found in the tDCS session. The lack of a delay was because the RT was shorter in the tDCS session than in the sham session for ambiguous conditions, but not for the unambiguous conditions. Our results support the hypothesis that anodal tDCS over the left IFC facilitates processing of lexically ambiguous words, although a modeling study suggests that the flow of current associated with tDCS can be more broadly distributed and is somewhat unpredictable (Datta et al., 2009).

Previous studies suggested that the left IFC is involved in the process of resolving lexical ambiguities. Broca's aphasics were impaired in their selection of contextually appropriate meanings for lexically ambiguous words (Swaab et al., 2003; Swaab, Brown, & Hagoort, 1998; Hagoort, 1993). In fMRI studies, the activity of the left IFC was observed in association with the comprehension of lexically ambiguous words (Bilenko et al., 2009; Gennari, MacDonald, Postle, & Seidenberg, 2007; Mason & Just, 2007; Zempleni et al., 2007; Rodd et al., 2005). Our MEG study also showed that the left IFC activates from 200 to 550 msec after the presentation of ambiguous words for selecting a contextual appropriate meaning from alternatives (Ihara et al., 2007). This study showed that anodal tDCS over the left IFC has the effect of behavioral facilitation in ambiguous conditions. This result supports the conclusions of previous studies and shows that the left IFC plays an essential role in processing lexical ambiguities.

The left IFC seems to have different functional roles regarding the anterior and posterior sites: the anterior site is involved in a control process that retrieves knowledge stored in the lateral temporal cortex, whereas the posterior site is involved in the selection of relevant knowledge among competing alternatives and controlled semantic inhibition (Grindrod, Bilenko, Myers, & Blumstein, 2008; Gold et al., 2006; Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Bunge, Wendelken, Badre, & Wagner, 2005; Cardillo, Aydelott, Matthews, & Devlin, 2004; Thompson-Schill, D'Esposito, & Kan, 1999). In this study, we applied tDCS over the anterior and posterior sites of the LIFC. Therefore, the shorter RT in the tDCS session suggests that anodal tDCS facilitated both controlled semantic retrieval in the anterior left IFC and meaning selection in the posterior IFC.

Most of the previous studies in the language domain applied tDCS over either Broca's area or Wernicke's area. Anodal stimulation over Broca's area enhanced language performance, that is, verbal fluency (Cattaneo et al., 2011; Iyer et al., 2005), grammar learning (de Vries et al., 2010), and picture naming (Fertonani et al., 2010), in healthy individuals and oral production, naming and word writing, in nonfluent aphasic patients (Marangolo et al., 2011). Similarly, anodal stimulation over Wernicke's area enhanced verbal learning (Flöel et al., 2008) and picture naming (Sparing et al., 2008) in healthy individuals and naming performance in individuals with fluent aphasia (Fridriksson et al., 2011) and nonfluent aphasia (Fiori et al., 2011). The performance improvements in the aphasic individuals were evaluated at 3 weeks (Fiori et al., 2011; Fridriksson et al., 2011) and 2 months (Marangolo et al., 2011) after the end of the tDCS sessions. The long-term effect suggests that tDCS may be useful as a neurorehabilitation therapy for aphasic patients.

On the other hand, few studies have focused on language comprehension (You et al., 2011). You and colleagues demonstrated that a 10-day session of cathodal tDCS over the right posterior superior temporal area, corresponding to Wernicke's area in the right hemisphere, improved auditory verbal comprehension in fluent aphasic individuals. They considered the possibility that the effect resulted from relaxing of the transcallosal inhibition of the lesional Wernicke's area by the corresponding area in the right hemisphere. The current report is the first to show that language comprehension is facilitated by anodal tDCS over the left IFC in healthy individuals. Although further studies are needed, these studies suggest that tDCS over the language area may be an adjuvant treatment approach for neurorehabilitation therapy to improve language comprehension in aphasic patients.

## Conclusion

Anodal tDCS over the left IFC decreased RT when participants in an experiment performed a semantic judgment task with lexically ambiguous words. The results of the experiment show that the left IFC is an essential region for lexical ambiguity processing.

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