The Role of Left IFG in Phonological, Syntactic and Semantic Processing of Homographic Words: A Transcranial Direct Current Stimulation (tDCS) Study

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Abstract

Reading ambiguous words (i.e., homographs) confronts the reader with the challenge of accessing and selecting from multiple semantic representations based on a single orthographic representation. For example, understanding the sentence "The fisherman sat on the *bank*" requires not only activation of the contextually relevant meaning (edge of a river), but also inhibition of the contextually irrelevant meaning (a financial institution). The present study investigated the role of the Left Posterior Inferior Frontal Gyrus (LpIFG, Brodmann Area 44-45) in selecting semantic information from among competing alternatives, by using brain stimulation (tDCS - transcranial Direct Current Stimulation).

Basically, a homograph is a written word *(bank)* with several semantic representations *(money/river)*. There are other types of homographs which are more complex and may have additional phonological (*tear* → /ter/, /tir/) or syntactic (*watch* → verb/noun) representations or both (*wind* → /wind/, /winde/, → verb/noun). However, because these complex types (especially those with multiple phonological representations) are less frequent in Indo-European languages, previous studies focused mainly on homophonic homographs (those associated with a single phonological representation). To investigate phonological and/or syntactic effects in lexical ambiguity resolution, the present study examined, for the first time, four types of homographs (all very common in Hebrew): (1) noun-noun homophonic homographs; (2) noun-noun heterophonic homographs; (3) noun-verb homophonic homographs; and (4) noun-verb heterophonic homographs. In addition, we examined the role of the LpIFG in the disambiguation of these

four types of homographs. In particular, we examined whether this area plays a general role in ambiguity resolution (i.e., the area is recruited in response to any type of ambiguity), or whether this region plays a more specific role (i.e., the area is recruited only in response to a particular type of ambiguity). This was investigated by excitatory brain stimulation, a technique which used by very few studies in this field, and only with the simple type of homograph. Here we studied the whole group of four homographs with brain stimulation, and it is another novelty of the current study.

Selection processes were measured by using a semantic decision task that requires inhibiting an irrelevant meaning of an ambiguous word (Gernsbacher, Varner, & Faust, 1990). During the task, participants were asked to read sentences and decide whether a target word, that was presented immediately after reading the sentence, is related to the meaning of the sentence, or not. We compared response latencies and accuracy for semantically unrelated targets ("no" responses) in two conditions: In the ambiguous condition, the sentences were biased towards the subordinate (less frequent) meaning of the final ambiguous word (e.g. "The fisherman sat on the bank"), and the target (e.g, money) was related to the irrelevant (dominant) meaning. In the unambiguous condition, the sentence and the target were identical except that the final ambiguous word (e.g., bank) was replaced with an unambiguous control word (e.g., "The fisherman sat on the shore" - money). The ambiguity effect is the difference between these two conditions. In particular, slower/less accurate responses in the ambiguous condition were taken to reflect semantic interference from the contextually irrelevant meaning of the ambiguous word.

One hundred and eight native Hebrew speakers (60 females and 48 males) aged 24 (±4) participated in the study. In the first phase, three behavioral experiments were

conducted. The first experiment (N=22) examined phonological effects by comparing noun-noun heterophonic homographs with noun-noun homophonic homographs. The second (N=19), examined syntactic influences by comparing noun-verb homophonic homographs with noun-noun homophonic homographs. The third experiment examined syntactic influences in the presence of phonological ambiguity, by comparing noun-verb heterophonic homographs with noun-noun heterophonic homographs. In the second phase, two additional experiments (experiments 4 and 5) were conducted with brain stimulation (tDCS). In these experiments, the participants were administered with excitatory stimulation of 1.5 mA for 15 min. Experiment 4 (N=25) was identical to the first experiment and investigated phonological effects. Experiment 5 (N=24) was identical to the second Experiment and examined syntactic effects.

The behavioral results revealed a general ambiguity effect, indicating interference from the contextually irrelevant meaning of the ambiguous word, irrespective of type. That is, in all experiments, the ambiguous condition (The fisherman sat on the bank - money) was more difficult than the unambiguous condition (The fisherman sat on the shore – money). Importantly, the ambiguity effect was larger for heterophonic homographs (multiple phonological representations) than for homophonic homographs (a single phonological representation), but there was no significant difference between noun-verb homographs (multiple syntactic categories) and noun-noun homographs (a single syntactic category).

The results of the brain stimulation experiments showed that in the case of phonological ambiguity (heterophonic homographs like *tear*), the ambiguity effect (i.e., the difference between the ambiguous and the unambiguous conditions) was significantly

reduced in the active group compared to the sham group. However, in the case of semantic ambiguity, with or without syntactic ambiguity (noun-noun or noun-verb homophonic homographs, like *bank* or *watch*), there was no difference in the magnitude of the ambiguity effect between the active and the sham groups These findings are consistent with previous studies that identified the left posterior IFG as involved in phonological decision (e.g. Bitan et al., 2017).

This study is the first to investigate four types of homographs using an identical paradigm. This enabled us to examine phonological and/or syntactic effects in semantic ambiguity resolution. In addition, the role of the left posterior IFG in selecting semantic information from among competing alternatives was investigated by using brain stimulation (tDCS). The results of these tDCS experiments indicate an improvement in suppressing irrelevant meanings during phonological but not syntactic or semantic disambiguation. Further research is needed to examine the clinical and the educational implications of these results, to improve linguistic abilities in the phonological domain.