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Specifying the role of the left prefrontal cortex in word selection

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ABSTRACT

Word selection allows us to choose words during language production. This is often viewed as a competitive process wherein a lexical representation is retrieved among semantically-related alternatives. The left prefrontal cortex (LPFC) is thought to help overcome competition for word selection through top-down control. However, whether the LPFC is always necessary for word selection remains unclear. We tested 6 LPFC-injured patients and controls in two picture naming paradigms varying in terms of item repetition. Both paradigms elicited the expected semantic interference effects (SIE), reflecting interference caused by semantically-related representations in word selection. However, LPFC patients as a group showed a larger SIE than controls only in the paradigm involving item repetition. We argue that item repetition increases interference caused by semantically-related alternatives, resulting in increased LPFC-dependent cognitive control demands. The remaining network of brain regions associated with word selection appears to be sufficient when items are not repeated.

1. Introduction

Although seemingly easy, the complex act of producing language relies on a number of distinctly described processes. Among these, lexical selection refers to the act of choosing words as we speak and has been suggested to be the main selection mechanism in the production of single words (Levelt, 1989). It is often thought of as a competitive process wherein a lexical representation is retrieved among semantically-related alternatives (e.g., Levelt, 2001; Levelt, Roelofs, & Meyer, 1999; Roelofs, 2003). The left prefrontal cortex (LPFC), and in particular the left inferior frontal gyrus (LIFG, e.g., Schnur, Schwartz, Brecher, & Hodgson, 2006; Schnur et al., 2009; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Thompson-Schill et al., 1998) is thought to help overcome competition for word selection through top-down control. However, whether the left PFC is always needed or whether its involvement is task specific remains to be investigated. In this study, we directly tested this question by testing stroke survivors with injury to the left PFC as they performed two picture naming tasks known to affect word selection difficulty but varying in terms of item repetition.

1.1. Semantic interference as a probe to study word selection

Word selection is often thought of as being a competitive process. This notion is supported by a category of speech errors referred to as semantic errors. Here, the erroneous word produced is semantically-related to the word which should have been produced (i.e., the target word). In the following example, "put the milk in the oven", the target "refrigerator" was substituted with a semantically-related word, "oven". Word selection by competition is also supported by experimental findings. Notably, several picture-naming tasks elicit semantic interference effects. These semantic interference effects have traditionally been interpreted as reflecting increased difficulty in lexical selection (e.g., Damian, Vigliocco, & Levelt, 2001; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Kroll & Stewart, 1994; Lupker, 1979). We note however that there is debate as to whether or not semantic interference occurs directly at the level of lexical selection or prior to lexical selection. Whereas some argue the semantic interference effect reflects increased competition at the level of lexical selection (e.g., Damian et al., 2001; Howard et al., 2006), others prefer incremental learning accounts in which the semantic interference effect is explained by changes in the connection weights between semantic and lexical representations (Navarrete, Del Prato, & Mahon, 2012; Navarrete, Del Prato, Peressotti, & Mahon, 2014; Navarrete, Mahon, & Caramazza, 2010; Oppenheim, Dell, & Schwartz, 2010).

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Here we refer to word selection in a broader sense and assume this process to be sensitive to interference caused by semantically-related alternatives.

1.2. Paradigms used to study word selection

1.2.1. Blocked cyclic picture naming paradigm

In the blocked cyclic picture-naming paradigm, participants name pictures presented within semantically-homogeneous or heterogeneous contexts (Damian et al., 2001; see Kroll & Stewart, 1994, for a first version of the blocked naming paradigm). In this task, pictures are presented within semantically-homogeneous versus heterogeneous blocks and are repeated several times per block (these repetitions are referred to as cycles). For the second cycle onward, performance is worse in homogenous blocks, that is when pictures are of the same semantic category, compared to when they are of different semantic categories, in heterogeneous blocks. This behavioral effect has traditionally been interpreted as reflecting increased competition for word selection caused by the repetitive prior retrieval of words from the same semantic category (Belke, Meyer, & Damian, 2005; Damian et al., 2001; Kroll & Stewart, 1994; Rahman & Melinger, 2009; although see Janssen, Carreiras, & Barber, 2011; Janssen, Hernández-Cabrera, van der Meij, & Barber, 2014; Navarrete et al., 2012, 2014; for different interpretations).

Several neuroimaging, electrophysiological, and neuropsychological studies have used this paradigm to target brain regions associated with word selection difficulty and to assess the time-course of this process (Aristei, Melinger, & Abdel Rahman, 2011; Hocking, McMahon, & de Zubicaray, 2009; Janssen et al., 2011, 2014; Maess, Friederici, Damian, Meyer, & Levelt, 2002; Schnur et al., 2006, 2009). These have often reported an involvement of the left PFC, and in particular of the LIFG. More specifically, neuropsychological studies have shown that left PFC patients show a larger semantic interference effect than controls (Schnur et al., 2006) and right PFC patients (Ries, Greenhouse, Dronkers, Haaland, & Knight, 2014). In addition, BOLD signal in the LIFG but also in left temporal regions increases in semantically-homogeneous compared to semantically heterogeneous blocks (Hocking et al., 2009; Schnur et al., 2009). Electro- and magneto-encephalographic studies have highlighted a time-window going from approximately 200 to 400 ms post-stimulus presentation as being sensitive to semantic context in this paradigm (Aristei et al., 2011; Janssen et al., 2011; Maess et al., 2002; although see Janssen et al., 2014 for activity in a later time-window: 500–750 ms post-stimulus), which is in the time-window typically attributed to lexical selection (Indefrey, 2011; Indefrey & Levelt, 2004; Levelt et al., 1999; Strijkers & Costa, 2011).

1.2.2. Continuous picture naming paradigm

Semantic interference is also experimentally observed without separating pictures in distinct blocks. In the continuous naming paradigm (Brown, 1981; Howard et al., 2006), pictures from different semantic categories are interleaved with one another. Participants get increasingly slower each time they name a picture from a given semantic category (i.e., there is a monotonic increase in reaction times with ordinal position within categories). Howard et al. (2006) referred to this effect as the cumulative semantic interference effect and has been interpreted as reflecting increasing lexical selection difficulty (although see Navarrete et al., 2010). More specifically, these results have been taken to demonstrate cumulative interference for word selection caused by prior selection of other exemplars of the same semantic category (Howard et al., 2006). Similarly to the blocked picture-naming paradigm, the semantic interference effect in the continuous naming paradigm has been used to probe lexical selection by chronometric, electrophysiological, and neuroimaging studies (Costa, Strijkers, Martin, & Thierry, 2009; de Zubicaray, McMahon, & Howard, 2013; Llorens, Trébuchon, Riès, Liégeois-Chauvel, & Alario, 2014).

Electrophysiological results have shown that event-related potentials are sensitive to the number of members of a semantic category named prior to the current one starting around 200 ms after stimulus onset (Costa et al., 2009; see however Llorens et al., 2014, for a non-replication of Costa et al., 2009), similarly as in the blocked cyclic picture-naming paradigm. Using perfusion fMRI, de Zubicaray et al.'s (2013) results suggest the left perirhinal cortex and left middle portion of the middle temporal gyrus (MTG) are involved in word selection using this paradigm as signal in these regions increased monotonically with ordinal position, similarly as for reaction times. Signal changes were also found in the LIFG and were affected by ordinal position. However, this change was not monotonic as in the other areas and signal decrease was observed in three of the five ordinal positions. This makes the association of this region with word selection as involved in this paradigm less clear. Neuroimaging studies looking at brain correlates of semantic interference in the continuous naming paradigm are however scarce. This could be explained by the fact neuroimaging studies typically require a critical number of trials per condition to address signal to noise issues, which is difficult to reach in this particular paradigm.

1.3. Role of the left PFC in word selection

While a similar theoretical account has been made for the semantic interference effects elicited by both paradigms (Oppenheim et al., 2010), recently a few studies have suggested that an additional mechanism is likely involved in the blocked versus the continuous paradigm (Belke & Stielow, 2013; Navarrete et al., 2012; Pisoni, Papagno, & Cattaneo, 2012). This argument is based on the fact these tasks differ drastically in terms of design (blocked vs. continuous), item repetition, as well as prior familiarization to the pictures before the experiment. These differences have been shown to affect the electrophysiological signal: event-related potentials associated with these paradigms have different time-courses and topographies (Llorens et al., 2014). Moreover, semantic interference in the blocked cyclic paradigm is generally not cumulative (in the sense that the semantic interference does not increase as a function of the factor cycle), whereas it is in the continuous paradigm (Belke & Stielow, 2013; see however Navarrete et al., 2014). Based on neuropsychological evidence (e.g., Schnur et al., 2006), Belke and Stielow (2013) suggest this additional mechanism present in the blocked cyclic picture naming paradigm may be a top-down control process hosted in the LIFG which biases the level of activation of lexical-semantic representations towards the task relevant items. This knowledge of which items are in the task is not present in the continuous paradigm, not allowing this process to take place. More specifically, the authors argue that in both heterogeneous and homogeneous blocks, this top-down biasing process optimizes lexical access and counters the cumulative cost in the homogeneous blocks. This process, however, does not eliminate the semantic interference effect, which the authors interpret as reflecting increased competition between semantically-related representations in the homogeneous blocks compared to heterogeneous blocks. They make the prediction that this top-down biasing process should not be involved in the continuous naming paradigm given that there, semantic interference is cumulative. If this process is not involved in the continuous paradigm, then patients with LIFG damage should not show a larger cumulative semantic interference effect than controls. The present study directly tests this prediction in patients with left PFC damage involving the LIFG.