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Brain mechanisms of semantic interference in spoken word production: An anodal transcranial Direct Current Stimulation (atDCS) study

Marcus Meinzer [a], Özlem Yetim [a], Katie McMahon [b], Greig de Zubicaray [c,*]

[a] Centre for Clinical Research, University of Queensland, Brisbane, Australia
[b] Centre for Advanced Imaging, University of Queensland, Brisbane, Australia
[c] Faculty of Health and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia

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ABSTRACT

When naming pictures, categorically-related compared to unrelated contexts typically slow production. We investigated proposed roles for the left inferior frontal gyrus (LIFG) and posterior middle and superior temporal gyri (pMTG/STG) in mediating this semantic interference effect. In a three-way, cross-over, sham-controlled study, we applied online anodal transcranial Direct Current Stimulation (atDCS) to LIFG or pMTG/STG while 24 participants performed parallel versions of the blocked cyclic naming paradigm. Significant effects of semantic context and cycle, and interactions of context and cycle, were observed on naming latencies in all three stimulation sessions. Additionally, atDCS over left pMTG/STG facilitated naming in related blocks from the second cycle onward, significantly reducing but not eliminating the interference effect. Applying atDCS over left LIFG likewise reduced the magnitude of interference compared to sham stimulation, although the facilitation was limited to the first few cycles of naming. We interpret these results as indicating semantic interference in picture naming reflects contributions of two complementary mechanisms: a relatively short-lived, top-down mechanism to bias selection and a more persistent lexical-level activation mechanism.

1. Introduction

Our everyday speech is heavily influenced by the context in which it occurs. Some contexts can facilitate *lexical access* – the process by which words are retrieved from long-term memory (i.e., the mental lexicon) – while others can interfere with it, slowing production and making it more prone to errors. Much of our knowledge about context effects during spoken word production comes from experimental investigations of picture naming in healthy participants and patients with acquired language impairments (i.e., aphasia). Manipulations of semantic contexts are of particular interest to psycholinguists, as both the speed and accuracy of production are known to vary according to the nature of the conceptual relationship and the type of experimental naming paradigm employed (see Mahon, Costa, Peterson, Vargas, & Caramazza, 2007, for review).

A reliably reported finding is that categorically related contexts hamper picture naming compared to unrelated contexts. One experimental paradigm that has been used regularly to elicit semantic interference effects in both healthy participants and patients with aphasia (PWA) is the blocked cyclic naming paradigm. The paradigm involves small blocks of pictures (e.g., 4–6) presented repeatedly over several cycles (e.g., 4–6). Related/homogeneous blocks comprise category exemplars (e.g., all animals) while unrelated/heterogeneous blocks comprise pictures from different categories (e.g., animals, vehicles, furnitures, fruit). Healthy participants are typically slower to name objects in related compared to unrelated blocks when they are repeated from the second cycle onward (Damian & Als, 2005; Damian, Vigliocco, & Levelt, 2001; Kroll & Stewart, 1994), and PWAs typically show increased error rates in related blocks (e.g., Biegler, Crowther, & Martin, 2008; Harvey & Schnur, 2015; McCarthy & Kartsounis, 2000; Riès, Greenhouse, Dronkers, Haaland, & Knight, 2014; Schnur, Schwartz, Brecher, & Hodgson, 2006; Wilshire & McCarthy, 2002).

Theoretical accounts of the interference effect in blocked cyclic naming propose it arises during conceptual processing or in the connections between conceptual and lexical levels of processing, i.e., via a bottom-up, domain-specific mechanism (see Belke, 2013; Oppenheim, Dell, & Schwartz, 2010 for reviews). These accounts assume multiple, conceptually-related candidates become activated during lexical access, with categorically related

* Corresponding author at: Faculty of Health and Institute of Health and Biomedical Innovation, Queensland University of Technology, Kelvin Grove, Brisbane, QLD 4059, Australia.

E-mail address: greig.dezubicaray@qut.edu.au (G. de Zubicaray).

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contexts priming the activation levels of these candidates via feature sharing. Yet, there is disagreement about the mechanism(s) for selecting target words for production. The predominant mechanism suggested in the literature is competitive lexical selection, in which the activation levels of all candidates (target and non-target) influence production (e.g., via the Luce ratio; Levelt, Roelofs, & Meyer, 1999). According to this account, selection of the target utterance is made more difficult in related contexts due to the priming of conceptual-to-lexical representations raising the lexical activation levels of competitors. An alternative account assumes non-competitive selection is accomplished when a predetermined activation threshold is reached. Using the latter type of mechanism, Oppenheim et al. (2010) were able to simulate the semantic interference effect by strengthening connections between conceptual and lexical representations of each target while also weakening co-activated non-target representations.

Accounts of the semantic interference effect have also begun to incorporate information from lesion, neuroimaging and non-invasive brain stimulation studies (e.g., Belke & Stielow, 2013; Oppenheim et al., 2010; Schnur et al., 2009). All of these neuroanatomically-informed accounts agree on a prominent role for the left posterior middle and superior temporal gyri (pMTG/STG) in mediating bottom-up, lexical–semantic retrieval processes. The left inferior frontal gyrus (LIFG) has also been proposed to play a domain-general, top-down role in selection processes (e.g., Heim, Eickhoff, Friederici, & Amunts, 2009), although the nature of this role in resolving semantic interference varies according to the different accounts. For example, Schnur et al. (2009) proposed that resolution of lexical competition in the block cyclic naming paradigm required LIFG involvement to top-down bias interactions among incompatible, non-target representations to facilitate selection. Oppenheim et al. (2010) subsequently implemented a computational mechanism for competitive selection – "tentatively" linked to the LIFG – to boost all (i.e., target and non-target) lexical activity until the difference between the most highly active candidate and the next most active exceeds a threshold for selection. Belke and Stielow (2013) offered a similar interpretation in which a top-down control mechanism in working memory mediated by the LIFG biases lexical selection based on a representation of the task. According to this account, participants encode the members of the target object set as part of the task representation during the first presentation cycle, and subsequently use this representation to top-down bias the relevant set members for selection. The bias facilitates target selection in unrelated blocks as it is applied to only one exemplar from the different categories, whereas it is applied to several, within-set category exemplars in related blocks, i.e., more top down control is needed to curtail the bottom-up competition. Belke and Stielow (2013) concluded "It appears that any future model of word production unavoidably faces the challenge of specifying how left frontal mechanisms of domain-general cognitive control interact with paradigmatic interference during lexical-semantic encoding." (p. 23).

The neuropsychological evidence cited in support of left pMTG/STG involvement in blocked cyclic naming is relatively consistent. For example, the lesion-symptom mapping (LSM) and perfusion neuroimaging studies of Harvey and Schnur (2015) and de Zubicaray, Johnson, Howard, and McMahon (2014) show good agreement with clusters reported with peak maxima with Montreal Neurological Institute (MNI) atlas coordinates of −52, −40, −5 and −46, −42, 2, respectively for semantic interference. The non-invasive brain stimulation studies of Pisoni, Papagno, and Cattaneo (2012) and Krieger-Redwood and Jefferies (2014) likewise showed significant effects targeting sites corresponding to MNI coordinates −50, −46, 1 and −54, −49, −2, respectively (but see Section 4 below). However, the same cannot be said for the evidence concerning LIFG involvement.

Functional neuroimaging studies in healthy participants have not consistently observed differential activity in the LIFG (e.g., de Zubicaray et al., 2014; Schnur et al., 2009), while studies of aphasics with LIFG lesions have produced variable results for interference effects in error rates and naming latencies, suggesting potentially dissociable mechanisms (e.g., Biegler et al., 2008; Harvey & Schnur, 2015; Riès et al., 2014; Schnur et al., 2009). For example, LIFG activity can be elicited more generally by naming errors, i.e., in the absence of semantic context manipulations (e.g., Abel et al., 2009). Interestingly, while de Zubicaray et al.'s (2014) fMRI study examined only activity associated with correct naming performance and did not observe significant differential LIFG responses, Schnur et al.'s (2009) analyses combined erroneous and correct trials, and they observed a positive correlation between LIFG activity and error rates. However, a similar correlation was not observed with left temporal cortex fMRI responses.

One factor complicating interpretations of the neuropsychological evidence is that the blocked cyclic naming paradigm might involve contributions from *two* separate mechanisms: a short-lived semantic priming effect in the first presentation cycle and a longer-lasting interference effect emerging with repetition in subsequent cycles (see Abdel Rahman & Melinger, 2007; Belke & Stielow, 2013; Crowther & Martin, 2014; Damian & Als, 2005; Krieger-Redwood & Jefferies, 2014; Navarrete, Del Prato, & Mahon, 2012). These two different effects might reflect relative differences in conceptual vs. lexical processing. Damian and Als (2005) were the first to propose this dichotomy based on the observation of faster naming latencies in related blocks in the first cycle (see Belke & Stielow, 2013; Navarrete, Del Prado, Peressotti, & Mahon, 2014). Yet, the majority of neuroimaging, lesion and brain stimulation investigations have analyzed data averaged over all presentation cycles (for review, see de Zubicaray et al., 2014). Hence, data from these studies could reflect semantic priming and lexical selection mechanisms attributable to LIFG and/or pMTG/STG involvement, respectively. Semantic priming effects in LIFG have been observed reliably across neuroimaging studies (for reviews see Badre & Wagner, 2007; Lau, Phillips, & Poeppel, 2008). Further, PWAs typically have large lesions extending throughout perisylvian cortex, potentially impacting more than one critical region or mechanism involved in task performance, making localization inferences difficult (e.g., Biegler et al., 2008; Harvey & Schnur, 2015; McCarthy & Kartsounis, 2000; Riès, Greenhouse, Dronkers, Haaland, & Knight, 2014; Schnur et al., 2006; Wilshire & McCarthy, 2002).

Recently, non-invasive brain stimulation methods have been applied to support causal inferences about cortical regions involved in spoken word production. These methods are able to be applied "online" (i.e., during performance of experimental paradigms) and "offline" (i.e., prior to performance). The two most frequently applied of these methods have been transcranial direct current and repetitive magnetic stimulation (see Hartwigsen, 2014 for review). Transcranial Direct Current Stimulation (tDCS) involves modulating cortical functioning by means of a weak electrical current projected between scalp-affixed electrodes. The most reliable effects on cognition have been reported for anodal tDCS that facilitates neural firing (for review, see Jacobson, Koslowsky, & Lavidor, 2012). Online and offline stimulation both to LIFG and posterior temporal cortex have been reported to speed naming latencies in healthy participants (e.g., Holland et al., 2011; Sparing, Dafotakis, Meister, Thirugnanasambandam, & Fink, 2008). By contrast, offline repetitive TMS (rTMS) is designed to inhibit/disrupt neural activity temporarily ("virtual lesioning"), by passing a short, strong current through a coil placed over the target area, without introducing potential experimental confounds associated with online TMS protocols (e.g., auditory clicks, somatosensory sensations) that either facilitate or disrupt process-