BRAIN RESEARCH 1586 (2014) 130–142

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Brain Research

Research Report

Electrophysiological evidence that inhibition supports lexical selection in picture naming

Zeshu Shao[a,*], *Ardi Roelofs*[a,b], *Daniel J. Acheson*[a,b], *Antje S. Meyer*[a,b]

[a]*Max Planck Institute for Psycholinguistics, PO Box 310, 6500 AH Nijmegen, The Netherlands*
[b]*Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, The Netherlands*

ARTICLE INFO

Article history:
Accepted 6 July 2014
Available online 16 September 2014

Keywords:
Delta plot
Lexical selection
Inhibition
N2
Picture naming

ABSTRACT

We investigated the neural basis of inhibitory control during lexical selection. Participants overtly named pictures while response times (RTs) and event-related brain potentials (ERPs) were recorded. The difficulty of lexical selection was manipulated by using object and action pictures with high name agreement (few response candidates) versus low name agreement (many response candidates). To assess the involvement of inhibition, we conducted delta plot analyses of naming RTs and examined the N2 component of the ERP. We found longer mean naming RTs and a larger N2 amplitude in the low relative to the high name agreement condition. For action naming we found a negative correlation between the slopes of the slowest delta segment and the difference in N2 amplitude between the low and high name agreement conditions. The converging behavioral and electrophysiological evidence suggests that selective inhibition is engaged to reduce competition during lexical selection in picture naming.

1. Introduction

An important goal of cognitive psychology is to understand how humans and animals make choices. For instance, choices are made between an immediate small reward and a delayed larger reward, between taking a left turn or a right turn in a maze, or, most relevant to the present work, between calling an object a *sofa* or a *couch*. Many theories of choice behavior invoke the concept of top-down inhibition, broadly defined as mechanisms that lead to the deactivation or suppression of some response tendencies to the benefit of others (e.g., Kok, 1999). The present work concerns the role of top-down inhibition in speaking, specifically in the selection of appropriate words from a candidate set.

There is a substantial body of work on the role of top-down inhibition in non-linguistic tasks. Commonly used tasks include the stop-signal task, where participants plan a response but must withhold it when a stop signal is presented on a minority of the trials (Logan and Cowan, 1984); the anti-saccade task, where participants see a flashing cue on either the left or right side of a screen and have to shift their attention and gaze quickly to the opposite side of the screen (Hallett, 1978); and the Eriksen flanker task, a choice-response task where participants choose a response to a central target stimulus that is flanked by non-target stimuli that are congruent or incongruent with the response to the target (Eriksen and Eriksen, 1974). Forstmann et al. (2008) distinguished between nonselective response inhibition,

*Corresponding author at: Max Planck Institute for Psycholinguistics, PO Box 310, 6500 AH Nijmegen, The Netherlands.
E-mail address: Zeshu.Shao@mpi.nl (Z. Shao).

http://dx.doi.org/10.1016/j.brainres.2014.07.009
0006-8993/© 2014 Elsevier B.V. All rights reserved.

which is engaged to stop any planned motor response, and selective response inhibition, which is recruited to selectively inhibit specific responses competing with a target response. They suggest that selective inhibition plays an important role in decision making.

The recruitment of selective inhibition in a task can be inferred from a delta plot analysis of reaction times (RTs). Delta plots show the size of an experimental effect (e.g., the RT difference between a congruent and an incongruent condition) as a function of response speed (De Jong et al., 1994; Ridderinkhof, 2002; Ridderinkhof et al., 2005; Van Campen et al., 2014). As shown by Ridderinkhof (2002) and others, the size of experimental effects (i.e., delta) typically increases with increasing RT: Slower reactions are accompanied by larger effects. However, this increase in effect size is counteracted when selective inhibition is applied. A hallmark of selective inhibition is that it needs time to be recruited (for reviews see Proctor et al., 2011; Van den Wildenberg et al., 2011). Therefore, the slope of the slowest segment of the delta plot (i.e., the segment connecting the last two quantiles in the RT distribution) can indicate the recruitment of selective inhibition (Burle et al., 2002; Forstmann et al., 2008). Shallower or more negative slopes suggest that stronger top-down inhibition is applied (e.g., Forstmann et al., 2008; Ridderinkhof, 2002; Van den Wildenberg et al., 2011).

Although most work on inhibition concerns non-linguistic behavior, several studies have suggested that inhibition is also engaged in language processing. For example, bilingual speakers have been shown to use inhibition to suppress a non-target language (e.g., De Bruin et al., 2014; Guo et al., 2011; Misra et al., 2012; Jackson et al., 2001; Roelofs et al., 2011; Verhoef et al., 2009). There is also evidence suggesting that inhibition deficits contribute to the impaired speech production of children with specific language impairment (SLI; e.g., Henry et al., 2012; Im-Bolter et al., 2006; Seiger-Gardner and Schwartz, 2008; Spaulding, 2010). Moreover, several recent neuroimaging studies by de Zubicaray et al. have been taken to point towards the engagement of inhibition in object naming in monolingual adults (e.g., de Zubicaray et al., 2001, 2002, 2006). Specifically, in the picture–word interference paradigm (where participants name pictures accompanied by distractor words), de Zubicaray et al. (2001) found that bilateral orbitomedial prefrontal cortex was more strongly activated when pictures were accompanied by semantically related distractor words compared to a series of Xs (i.e., when lexical selection was more competitive). They concluded that their data confirmed the role of inhibition in reducing semantic interference during picture naming. It should be noted, however, that other investigators (e.g., De Bruin et al., 2014; Forstmann et al., 2008; Verhoef et al., 2009) have associated inhibition with right inferior frontal cortex rather than with orbitomedial prefrontal cortex, as de Zubicaray et al. did.

The current study presents EEG evidence for the involvement of selective inhibition in word production, specifically in picture naming. In order to name a picture, a speaker must perceptually process and conceptually encode the picture, select an appropriate lexical item (a lemma) from the mental lexicon, morphologically, phonologically, and phonetically encode the corresponding word form, and finally generate the motor commands of articulation (e.g., Levelt et al., 1999). During the early processes of conceptual encoding and lexical selection, several closely related lexical concepts and the corresponding names may become simultaneously activated (e.g., when an object could either be called a *sofa* or *couch*), and the speaker must then select the most appropriate item amongst those that are active. Several models of lexical access propose that the process of lexical selection is competitive, such that the selection of a target is hindered by co-activation of competitors (e.g., Abdel Rahman and Melinger, 2009; Bloem and La Heij, 2003; Howard et al., 2006; Levelt et al., 1999; Piai et al., 2014; Roelofs, 1992, 2003; Starreveld and La Heij, 1996). In other models, lexical selection is not seen to be a competitive process: A target is selected as soon as it has reached a threshold of activation regardless of the activation levels of other lexical items (see Finkbeiner and Caramazza, 2006; Mahon et al., 2007).

In models assuming that lexical selection is a competitive process, the competition could be resolved, and selection achieved, by boosting the activation of a target (e.g., Roelofs, 1992, 2003), by suppressing the activation of the competitors, or both. In earlier work measuring RTs during picture naming (Shao et al., 2012, 2013, 2013), we found evidence suggesting the involvement of non-selective inhibition (assessed by the stop-signal task) and selective inhibition (assessed by delta plot analyses) in word production. In these studies, we used the picture–word interference paradigm, where participants named pictures (e.g., a picture of a *dog*) in the presence of semantically related or unrelated distractor words (e.g., *cat* vs. *tree*), and the semantic blocking paradigm, where participants repeatedly named small sets of pictures which all belong to the same semantic category (e.g., animal) or to different categories. Replicating earlier findings (e.g., Abdel Rahman and Melinger, 2007; Belke, 2008; Schriefers et al., 1990), we obtained semantic interference in both experiments. In addition, we found positive correlations between stop-signal RT and picture naming RT (Shao et al., 2012, 2013), as well as between the slope of the slowest delta segment and the mean magnitude of the semantic interference effects in the blocking paradigm (Shao et al., 2013) and in the picture-word interference paradigm (Shao et al., 2013). We proposed that selective inhibition is applied during the competitive lexical selection process. In models where selection is not taken to be competitive (e.g., Finkbeiner and Caramazza, 2006), selective inhibition could affect later processes, namely the selection of the correct motor plan for the articulation of the word from a set of candidate plans stored in an output buffer. In short, none of the existing models of word production refer to selective inhibition. However, based on our earlier work and related research, we propose that selective inhibition could play an important role in lexical selection. The goal of the present study was to test this hypothesis in a new paradigm where no strong competitors were introduced.

Both of the paradigms used in the earlier studies of the involvement of selective inhibition in word production induced variation in the difficulty of lexical selection through the presence or absence of highly salient competing stimuli to the targets. In the picture–word interference paradigm the competitors are the words presented together with the pictures; in the semantic blocking paradigm the competitors