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Electrophysiology of executive control in spoken noun-phrase production: Dynamics of updating, inhibiting, and shifting

Katarzyna Sikora [a,*], Ardi Roelofs [a], Daan Hermans [b,c]

[a] Radboud University, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Montessorilaan 3, 6525 HR, Nijmegen, The Netherlands
[b] Radboud University, Behavioural Science Institute, Montessorilaan 3, 6525 HR, Nijmegen, The Netherlands
[c] Royal Dutch Kentalis, Petrus Dondersplein 1, 5271 AA, Sint-Michielsgestel, The Netherlands

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ABSTRACT

Previous studies have provided evidence that updating, inhibiting, and shifting abilities underlying executive control determine response time (RT) in language production. However, little is known about their electrophysiological basis and dynamics. In the present electroencephalography study, we assessed noun-phrase production using picture description and a picture-word interference paradigm. We measured picture description RTs to assess length, distractor, and switch effects, which have been related to the updating, inhibiting, and shifting abilities. In addition, we measured event-related brain potentials (ERPs). Previous research has suggested that inhibiting and shifting are associated with anterior and posterior N200 subcomponents, respectively, and updating with the P300. We obtained length, distractor, and switch effects in the RTs, and an interaction between length and switch. There was a widely distributed switch effect in the N200, an interaction of length and midline site in the N200, and a length effect in the P300, whereas distractor did not yield any ERP modulation. Moreover, length and switch interacted in the posterior N200. We argue that these results provide electrophysiological evidence that inhibiting and shifting of task set occur before updating in phrase planning.

1. Introduction

Fluent language production is important for successful communication. An average speaker can produce some 150 words per minute with as little as about one error every 1000 words (Levelt, 1989). Although speaking is a highly practiced psychomotor skill, it requires executive control (e.g., de Zubicaray, Wilson, McMahon, & Muthiah, 2001; Roelofs, 2003; Roelofs & Piai, 2011; Schnur, Schwartz, Kimberg, Hirshorn, Coslett, & Thompson-Schill, 2009). Executive control refers to the regulative processes that ensure that our thoughts and actions are in accordance with our goals (e.g., Baddeley, 1996; Gilbert & Burgess, 2008; Logan, 1985; Posner, 2012). According to an influential proposal (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000), executive control includes updating and monitoring of working memory representations (*updating*), inhibiting of unwanted responses (*inhibiting*), and shifting between tasks or mental sets (*shifting*). The updating ability determines working memory capacity (cf. Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009). Previous behavioral studies have shown that the updating, inhibiting, and shifting abilities determine the response time (RT) of picture naming and picture description (e.g., Piai & Roelofs, 2013; Shao, Roelofs, & Meyer, 2012; Sikora, Roelofs, Hermans, & Knoors, 2015). However, little is known about the electrophysiological basis and dynamics of these abilities in language production. The aim of the present study was to obtain electrophysiological evidence on the dynamics of the involvement of updating, inhibiting, and shifting in spoken noun-phrase production.

Below, we first briefly review the RT evidence on the contributions of updating, inhibiting, and shifting to language production (Section 1.1). Next, we describe previous evidence on event-related brain potentials (ERPs) that inhibiting and shifting are generally associated with modulations of anterior and posterior N200 subcomponents, respectively, and updating with modulations of the P300 (Section 1.2). Then, we describe our experimental procedure, which consisted of overt noun-phrase production to describe pictures and a picture-word interference paradigm (Section 1.3). The procedure allows for measuring length, distractor, and switch effects, which have been shown to reflect the updating, inhibiting, and shifting abilities, respectively. In the remainder of this article, we report a study examining these effects in RTs and ERPs in language production (Sections 2 and 3). Finally, we discuss what our electrophysiological findings reveal

* Corresponding author: Katarzyna Sikora, Radboud University, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Spinoza Building B.02.40, Montessorilaan 3, 6525 HR Nijmegen, The Netherlands.
E-mail address: K.Sikora@donders.ru.nl (K. Sikora).

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about the dynamics of executive control in noun-phrase production (Section 4).

1.1. Contributions of updating, inhibiting, and shifting to language production

Theoretically, the updating, inhibiting, and shifting abilities are expected to contribute to language production. The updating ability is needed because speakers must keep in mind the intended goal of the conversation, monitor their performance and update the content of working memory while engaging in conceptual and linguistic processes (e.g., Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; Piai & Roelofs, 2013). Moreover, the inhibiting ability is required to suppress incorrect names that are co-activated during lexical selection (e.g., Shao, Roelofs, Acheson, & Meyer, 2014). Furthermore, the shifting ability is needed to switch between planning one type of phrase to another or switch from planning an utterance to monitoring the articulatory output (e.g., Levelt, 1989).

Recent studies have provided RT evidence that the updating, inhibiting, and shifting abilities contribute to language production. Shao et al. (2012) observed that updating ability was correlated with the mean RT of action naming but not of object naming, while inhibiting ability was correlated with the mean RT of both object and action naming. Action naming is typically more demanding than object naming. Thus, the correlation between updating ability and the mean RT of action but not object naming suggests that the engagement of updating is particular evident in demanding situations. Whereas Shao et al. (2012) obtained no correlation between updating ability and the mean RT of object naming, Piai and Roelofs (2013) observed that in a more demanding situation, namely picture naming during dual-task performance, the updating ability correlated with the mean RT of object naming. Shao et al. did not find a contribution of shifting to picture naming, but this may be due to the absence of some kind of switching in simple naming. To examine the contributions of updating, inhibiting, and shifting in a situation that requires actual switching, Sikora et al. (2015) asked participants to describe pictures of simple objects by producing noun phrases in Dutch. We describe the design and results of this study in some detail, because a similar design was used in the ERP study presented below.

In the study of Sikora et al. (2015), pictures were presented in color or black-and-white. In response to the colored pictures, participants produced determiner-adjective-noun phrases with the adjective referring to the color (e.g., “de groene vork”, the green fork), the *long* phrases. In response to the black-and-white pictures, they produced determiner-noun phrases without the adjective (e.g., “de vork”, the fork), the *short* phrases. In both cases, the determiner was a definite article, *de* or *het* in Dutch (and in another condition, not included in the present study, it was an indefinite article). In this task, the updating ability is needed because in planning the noun phrases, speakers have to conceptually identify the pictured object and retrieve from long-term memory a corresponding noun. For the long phrases, also the color needs to be identified and an adjective has to be retrieved from memory. Moreover, the appropriate gender-marked article needs to be retrieved. Following this, a syntactic structure has to be chosen and the determiner and noun, as well as the adjective for the long phrases, have to be serially ordered. Conceptual preparation and syntactic encoding are followed by morphophonological and phonetic encoding, and finally, articulation. The conceptual and linguistic processes require working memory (e.g., Levelt, 1989).

Given that more information needs to be derived from the picture, accessed in long-term memory, and manipulated in working memory for the long phrases than for the short phrases, the updating ability should be more strongly engaged when producing the long phrases. Consequently, the magnitude of the difference in RT between these phrase types, the *length effect*, was expected to reflect a speaker’s updating ability. To assess the contribution of the inhibiting ability, the pictures were combined with auditory distractor words, which could be congruent (i.e., the name of the picture, e.g., *vork*) or incongruent (the name of another, semantically related picture, e.g., *bord*, plate). The inhibiting ability was expected to be more strongly engaged with incongruent than congruent distractors. Consequently, the magnitude of the difference in RT between these distractor types, the *distractor effect*, was expected to reflect a speaker’s inhibiting ability. To assess the contribution of the shifting ability, the required phrase type (long or short) changed every second trial. Thus, two short phrases (for pictures in black-and-white) were followed by two long phrases (for pictures in color) and vice versa. A trial that repeats the previous phrase type (short preceded by short or long preceded by long) is a repeat trial, and a trial that does not repeat the previous phrase type (short preceded by long or long preceded by short) is a switch trial. Speakers need to engage the shifting ability on switch trials to enable to production of a different phrase type. The shifting ability should be more strongly engaged on switch than repeat trials. Consequently, the magnitude of the difference in RT between these trial types, the *switch effect*, was expected to reflect a speaker’s shifting ability. In addition to picture description RTs, the participants’ updating, inhibiting, and shifting abilities were measured using standard tasks to assess executive control. The operation-span and odd-one-out tasks (Conway et al., 2005) were used to assess verbal and nonverbal updating ability, respectively, the stop-signal task (Verbruggen, Logan, & Stevens, 2008) to assess nonverbal inhibiting ability, and the shape-color switching task (Miyake et al., 2000) to assess nonverbal shifting ability.

It was found that participants described the pictures slower in the long phrase than in the short phrase condition (the length effect), slower in the incongruent than in the congruent distractor condition (the distractor effect), and slower in the switch than in the repeat condition (the switch effect). The length effect in the RTs correlated with the verbal but not the nonverbal updating scores, while the distractor effect correlated with the inhibiting scores. No correlation was found between the switch effect in the mean RTs and the shifting scores. However, the shifting scores correlated with the switch effect in the normal part of the underlying RT distribution. These results suggest that updating, inhibiting, and shifting each influence the speed of phrase production, thereby demonstrating a contribution of all three executive control subabilities to language production.

A switch effect was obtained for the short phrases but not for the long phrases. This observation corresponds to the asymmetry in switch costs that is often obtained in task switching (e.g., Allport & Wylie, 1999, 2000; Gilbert & Shallice, 2002; Yeung & Monsell, 2003) and language switching (e.g., Jackson, Swainson, Cunnington & Jackson, 2001; Meuter & Allport, 1999). According to Allport and Wylie (1999, 2000), the asymmetrical switch effect is caused by differential task-set inertia, which refers to the idea that the irrelevant task set of the previous trial is still active on the current trial and needs to be actively disengaged. Colored pictures allow as responses both long phrases and short phrases, whereas black-and-white pictures only allow short-phrase responses. Therefore, to prevent inadvertent short-phrase responses to colored pictures, the task set for the short phrases may be inhibited and the task set for the long phrases may be enhanced. In contrast, on trials with black-and-white pictures, inhibition of long phrases and enhancement of short phrases is not needed. As a consequence, disengagement from the previous task set will take much longer in switching to short phrases than to long phrases, as observed by Sikora et al. (2015). One of the aims of the present ERP