EXECUTIVE CONTROL IN LANGUAGE PRODUCTION BY ADULTS AND CHILDREN WITH AND WITHOUT LANGUAGE IMPAIRMENT

Katarzyna Anna Sikora

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Cover designed by Dawid Sikora
Dutch translation by Johanna de Vos

Executive control in language production by adults and children with and without language impairment

Doctoral Thesis

to obtain the degree of doctor
from Radboud University Nijmegen
on the authority of the Rector Magnificus prof. dr. J.H.J.M. van Krieken,
according to the decision of the Council of Deans
to be defended in public on Friday, April 13, 2018
at 10.30 hours

by

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proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.H.J.M. van Krieken,
volgens besluit van het college van decanen
in het openbaar te verdedigen op vrijdag 13 april 2018
om 10.30 uur precies

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Nothing in life is to be feared; it is only to be understood.

- Marie Skłodowska Curie

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CHAPTER 1

Introduction

An average child learns language without difficulty. Usually around the first birthday, children are able to produce a few words and they continue to expand their vocabulary. By the age of 6 years, their basic language skills are mostly developed. However, there is a variability in the speed of language acquisition and unfortunately some children fail to acquire age-appropriate language. Similarly, variance in the language abilities is present among adult speakers. Individual differences in language skills may be attributed to various factors. Some of these differences can be explained by differences in executive control ability (e.g., Roelofs 2008; Shao, Roelofs, & Meyer, 2012). Executive control refers to higher-level cognitive processes that regulate our thoughts and behaviour (e.g., Baddeley, 1996; Barkley, 2012; Gilbert & Burgess, 2008; Logan, 1985). Previous research suggested that in some developmental conditions, such as specific language impairment (SLI; Leonard et al., 2007; Montgomery, Magimairaj, & Finney, 2010) or ADHD (Bruce, Therlund, & Nettelbladt, 2006), language problems may be related to deficits in executive control. Moreover, it has been demonstrated that executive control contributes to speed of picture naming in healthy adults (Shao et al., 2012; Piai & Roelofs, 2013). However, little is known about the relation between executive control and more complex language production in both healthy and developmentally impaired speakers. The current thesis addresses this topic by investigating the influence of executive control on noun-phrase production in adults, in healthy children, and in children with specific language impairment.

In the remainder of this introduction, I briefly discuss three major components of executive control (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000) and their relation to language production in healthy adults, followed by a short discussion of executive control and language production in children with SLI. Next, I provide an overview of the current thesis, and describe the noun-phrase paradigm that I used to measure the impact of executive control on spoken language production.

Components of executive control

Following Miyake et al. (2000), executive control is often assumed to consist of three major components: updating and monitoring of working memory representations (*updating*), inhibiting of unwanted responses (*inhibiting*), and shifting between tasks or mental sets (*shifting*). Updating is the ability to actively manipulate the contents of working memory and to monitor incoming information in order to keep track of which information is relevant to the task and which is not. Moreover, updating involves replacing old, no longer relevant information with new information that is relevant to the task (e.g., Ecker, Lewandowsky, Oberauer, & Chee, 2010). Inhibiting is the ability to intentionally suppress dominant, automatic, or preponent responses (e.g., Aron, Robbins, & Poldrack, 2004; Forstmann, Jahfari, Scholte, Wolfensteller, Wildenberg, & Ridderinkhof, 2008). Finally, shifting is the ability to switch between multiple tasks, operations, or mental sets (e.g., Allport & Wylie, 2000; Monsell, 2003). It is the ability to enhance a relevant task set or to inhibit an irrelevant task set, as well as the ability to overcome previous enhancement or inhibition. According to Miyake et al., the three executive functions are to some extent separable but they are also moderately correlated, which suggests some underlying commonality.

Executive control and language production in adults

In language production, the role of the updating ability may be to manage communicative goals as well as to monitor and schedule conceptual and linguistic processes. Previous studies have demonstrated that in adults, better updating ability is related to the speed of picture naming (Shao et al., 2012; Piai & Roelofs, 2013). In a picture naming task, the updating ability may determine how well a speaker keeps in mind instructions of the task (e.g., to be fast and accurate) while engaging in conceptual and linguistic processes. In more complex spoken language production, such as in having conversation, the updating ability may be additionally needed to evaluate performance and to update the content of working memory more extensively.

The inhibiting ability has been also found to be important for language production. Shao et al. (2012) demonstrated that speakers with better inhibiting ability were faster in a picture naming task. To correctly name a picture, appropriate lemmas have to be retrieved. Lemma retrieval is one of the stages of word production and it is subject to competition by other co-activated lemmas (Levelt, 2001; Roelofs, 1992, 2003). For example, if a picture of a dog has to be named, the target concept DOG will activate the lemma of the word *dog*, but activation will also spread to the lemmas of semantically related words such as *animal* and *cat*. Inhibiting these competing lemmas may speed up the selection of the target lemma. Speakers with better inhibiting ability appear to be more successful in resolving lexical competition. Moreover, in language production, the inhibiting ability may also be important to ignore environmental distractions, for instance, in a situation when we have a conversation in a noisy environment, such as talking to a friend on a busy street.

It is not clear how shifting ability would be involved in simple word production such as in a picture naming task. Indeed, Shao et al. (2012) did not find a relation between shifting ability and the speed of picture naming. However, it is plausible that shifting ability is needed for more complex language production, for instance, to switch from planning one type of phrase to another or from planning an utterance to listening to a conversation partner. Therefore, to identify the contribution of the shifting ability to spoken language production, it is necessary to study it in a context that more explicitly engages this ability.

Executive control in children with SLI

SLI is a developmental disorder characterized by impaired language abilities that cannot be attributed to hearing, neurological or intellectual deficit (e.g., Bishop, 2006; Leonard, 2014). Although the majority of children with SLI experience expressive language problems, most of the studies have concentrated on language comprehension (e.g., Montgomery, 1995, 2002a, 2002b, 2004; Montgomery & Windsor, 2007; Montgomery & Evans, 2009). As a consequence, little is known about language production in SLI. Therefore, there is a need for more research on language production difficulties in those children.

Recent studies demonstrated that children with SLI experience also difficulties in nonlinguistic domains, such as executive control (e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006). In particular, studies have demonstrated that children with SLI are impaired in verbal updating ability as well as in inhibiting ability (e.g., Chiat & Roy, 2007; Henry et al., 2012; Im-Bolter et al., 2006; Petruccelli, Bavin, & Bretherton, 2012; Vissers et al., 2015). However, findings on nonverbal updating ability are less consistent. Some studies demonstrated a deficit in nonverbal updating ability for SLI (e.g., Henry et al., 2012; Vugs, Hendriks, Cuperus, & Verhoeven, 2014) while several other studies failed to find differences between SLI and TD children (e.g., Archibald & Gathercole, 2006b; Lum, Conti-Ramsden, Page, & Ullman, 2012). Moreover, there is no consistent evidence for an impairment in shifting ability (e.g., Kapa & Plante, 2015). In this thesis, I report research that further investigated whether children with SLI show a deficit in all or only some components of executive control. Studying the relation between executive control and language production in SLI is important for two reasons. First, gaining better insight in this topic may benefit development and improvement of therapies for children with SLI. Second, it may contribute to our understanding of language production and its relation to other cognitive functions.

Present thesis

The aim of the current thesis is to further investigate the relation between executive control and language production in typical and developmentally impaired speakers. Previous research presented some evidence that executive control is important for spoken language production. However, several questions have remained. To start with, it is unclear how the three components of executive control (i.e., updating, inhibiting, and shifting) are related to more complex forms of language production, like noun-phrase production. Moreover, little is known about the electrophysiological basis and dynamics of the impact of executive control on language production. Finally, it is not clear whether and how executive control contributes to the language difficulties in developmental disorders such as SLI. I aimed to address these issues with the following studies.

In Chapter 2, I report a study that examined how executive control influences spoken noun-phrase production in healthy adults. More specifically, I investigated whether the updating, inhibiting, and shifting abilities influence the speed of noun-phrase production. Importantly, the contribution of shifting ability was examined in a situation that more explicitly engages this ability.

In Chapter 3, I report a study that investigated the electrophysiological basis of the influence of executive control on language production. Previous studies have identified the N200 and P300 component of the event-related brain potential as electrophysiological correlates of executive control (e.g., Folstein & Van Petten, 2008; Jackson et al., 2001; Kok, 2001; Polich & Kok, 1995; Polich 2007). Updating has been found to be associated with modulations of the P300 component, and inhibiting and shifting with modulations of anterior and posterior N200 components, respectively. I examined whether the same electrophysiological components can be identified during noun-phrase production when the demand of updating, inhibiting and shifting increases.

In Chapter 4, I further investigated the source of the asymmetrical switch costs that were obtained in Chapters 2 and 3 in switching between short and long phrases. A switch cost asymmetry has often been observed in switching between tasks of different strength (e.g., Yeung & Monsell, 2003). I report a study that tested whether in language production tasks, asymmetrical switch costs can be attributed to overcoming attentional inhibition or enhancement.

In Chapter 5, I report a study that investigated whether children with SLI are impaired in all three components of executive control and whether their impairment in those components is reflected in their language production performance. To examine this, I compared the performance of children with SLI and typically developing (TD) on executive control tasks and on the noun-phrase production task.

In all chapters, I used a noun-phrase production task to measure the impact of executive control on spoken language production. Each study used a slightly modified version of the task. In the next section, I describe some of the main features of the task, and explain how the contributions of updating, inhibiting, and shifting were measured in this task.

The noun-phrase production paradigm

Figure 1 illustrates the noun-phrase production paradigm. Participants had to describe pictures presented in the middle of a computer screen while trying to ignore spoken distractors that were presented simultaneously with the pictures. The set of stimuli consisted of four drawings of simple objects (e.g., a chair) and four spoken distractors, which were the names of these objects. Participants had to describe all the pictures using noun phrases with an article (e.g., "the chair").

The picture names and the spoken distractors could be either two identical nouns (e.g., a picture of a chair combined with the spoken word *chair*), the *congruent* condition, or two different nouns (e.g., a chair combined with the word *lamp*), the *incongruent* condition. The inhibiting ability was assumed to be more strongly involved on the incongruent than on the congruent trials, and the magnitude of the difference in response time (RT) between these distractor types, the *distractor effect*, would reflect a speaker's inhibiting ability.

The pictures where either black-and-white or colored drawings. The participants were instructed to produce determiner-noun phrases when the presented picture was a black-and-white drawing, the *short phrase* condition (e.g., "the chair"). When the picture was presented in color, the participants had to produce a phrase that included an article, a color adjective, and the name of the object, the *long phrase* condition (e.g., "the blue chair"). The updating ability was assumed to be more strongly involved in the production of the long than of the short phrases, and the magnitude of the difference in RT between these phrase types, the *length effect*, was expected to reflect a speaker's updating ability.

The pictures were presented such that the required phrase type changed every second trial. Thus, in the trial sequence, two black-and-white pictures were followed by two colored pictures, which were followed by two black-and-white pictures, etc. This designed allowed us to measure picture description RT on *repeat* and *switch* trials. It was assumed that the shifting ability should be more strongly engaged on switch than on the repeat trials and that the magnitude of the difference in RT between these trial types, the *switch effect*, would reflect a speaker's shifting ability.

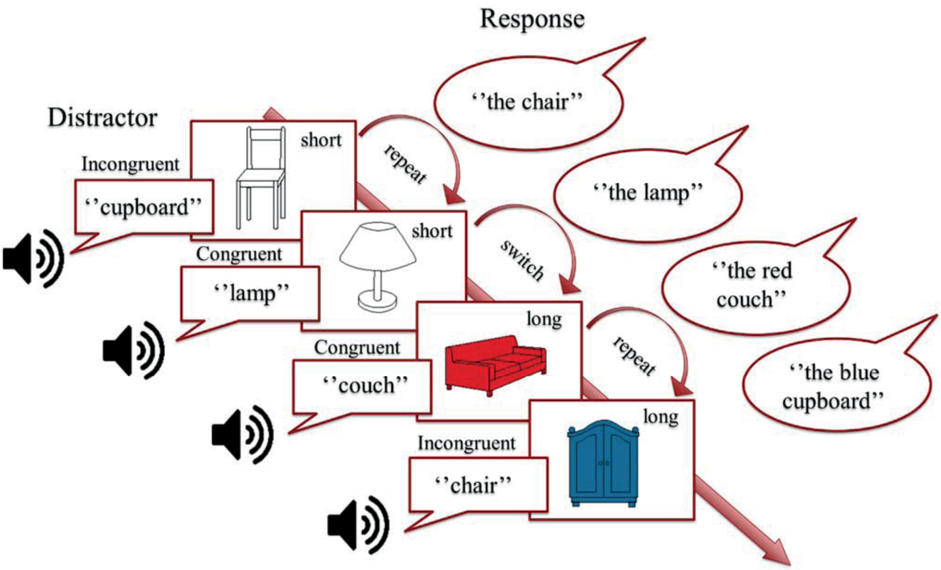

Figure 1: Example of the noun-phrase production task used in this dissertation (distractor effect = incongruent distractor – congruent distractor; length effect = long phrase – short phrase; switch effect = switch trials- repeat trials).


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CHAPTER 2

Executive control in spoken noun-phrase production: Contributions of updating, inhibiting, and shifting

This chapter appeared as: Sikora, K., Roelofs, A., Hermans, D., & Knoors, H. (2016). Executive control in spoken noun-phrase production: Contributions of updating, inhibiting, and shifting. *The Quarterly Journal of Experimental Psychology, 69*, 1719-1740.

Abstract

The present study examined how the updating, inhibiting, and shifting abilities underlying executive control influence spoken noun-phrase production. Previous studies provided evidence that updating and inhibiting, but not shifting, influence picture naming response time (RT). However, little is known about the role of executive control in more complex forms of language production like generating phrases. We assessed noun-phrase production using picture description and a picture-word interference procedure. We measured picture description RT to assess length, distractor, and switch effects, which were assumed to reflect, respectively, the updating, inhibiting, and shifting abilities of adult participants. Moreover, for each participant we obtained scores on executive control tasks that measured verbal and nonverbal updating, nonverbal inhibiting, and nonverbal shifting. We found that both verbal and nonverbal updating scores correlated with the overall mean picture description RTs. Furthermore, the length effect in the RTs correlated with verbal but not nonverbal updating scores, while the distractor effect correlated with inhibiting scores. We did not find a correlation 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 abilities to language production.

Introduction

Individuals learn to produce language long before they acquire other cognitive skills, such as solving mathematical equations or playing chess. However, the mechanisms underlying fundamental language production abilities are not simple. To begin with, in producing an utterance, a speaker needs to select and encode appropriate words. A well-known theory of word production distinguishes between two stages: lexical selection and word-form encoding (Levelt, 1989, 2001; Levelt, Roelofs, & Meyer, 1999). During the lexical selection stage, a lemma representing the syntactic properties of the word is retrieved, while during the word-form encoding stage the appropriate morphophonological and phonetic form is encoded (Levelt, 2001). Lexical selection seems to be subject to competition in that a number of co-activated lemmas compete for selection and their level of activation determines the speed of word production (Levelt, 2001; Piai, Roelofs, Jensen, Schoffelen, & Bonnefond, 2014; Roelofs, 1992, 2003). Moreover, in order to successfully complete an intended utterance, a speaker may need to allocate working memory capacity to the planning stages, monitor whether the internal or actually produced speech matches the intended utterance, and ignore environmental distractors (Roelofs, 2003, 2004; Roelofs & Piai, 2011). All these processes require some form of executive control, which refers to the higher-level processes that regulate our perceptions, thoughts, and actions (e.g., Baddeley, 1996; Barkley, 2012; Gilbert & Burgess, 2008; Logan, 1985; Meyer & Kieras, 1997; for a recent overview, see Goldstein & Naglieri, 2014).

Executive control is an umbrella term covering a number of abilities. According to an influential proposal by Miyake and colleagues (Miyake et al., 2000), executive control consists of three main components: updating and monitoring of working memory representations, inhibiting of unwanted responses, and shifting between tasks or mental sets (see also Collette et al., 2005; Friedman et al., 2008). Updating is the ability to monitor incoming information for relevance to the task at hand, and maintain or actively manipulate the contents of working memory (e.g., Ecker, Lewandowsky, Oberauer, & Chee, 2010). Inhibiting is the ability to lower the activation of unwanted dominant, automatic, or prepotent responses (e.g., Aron, Robbins, & Poldrack, 2004). Shifting is the ability to switch back and forth between multiple tasks, operations, or mental sets (e.g., Allport & Wylie, 2000; Monsell, 2003). In the context of language production, updating may include the ability to manage communicative goals as well as monitor and schedule conceptual and linguistic processes (e.g., Levelt, 1989). For example, in a picture naming task, the updating ability may determine how well a speaker keeps in mind the requirements of the task (e.g., to be fast and accurate) while engaging in conceptual and linguistic processes. The contribution of the inhibiting ability to language production may include the suppression of co-activated but incorrect lemmas. In order to correctly name a picture, a speaker may need to inhibit activated words different than the picture name (e.g., *dog*, *tail*, or *kitten* in naming a cat). The shifting ability may be engaged in language production, for example, when a speaker needs to switch from planning one type of phrase or sentence to another, from planning an utterance to monitoring output, or from planning an utterance to listening to a conversation partner.

Several types of evidence suggest that impaired language performance is associated with deficits in executive control, suggesting that executive control is important for skilled language performance. For example, individuals with developmental language disorder (Leonard et al., 2007; Montgomery, Magimairaj, & Finney, 2010), ADHD (Bruce, Therlund, & Nettelbladt, 2006), Parkinson's disease (Altmann & Troche, 2011; Bastiaanse & Leenders, 2009), or stroke-induced brain damage (Brownsett et al., 2014; Schnur et al., 2009; Schwartz et al., 2009) experience language problems that may be related to problems in executive control, to varying extents and in different ways. Moreover, recent studies have demonstrated that individual differences in the speed of language production in healthy young speakers are also related to differences in executive control abilities.

Shao, Roelofs, and Meyer (2012) presented evidence for involvement of different executive control components in picture naming in healthy participants. They found that better updating and inhibiting abilities lead to shorter response times (RTs) for picture naming. More specifically, better updating ability was associated with shorter mean RTs for action naming, while better inhibiting ability was associated with shorter mean RTs for both object and action naming. Picture naming RTs did not correlate with shifting ability. Analyses of the RT distributions suggested differential engagement of updating and inhibiting abilities across the experimental trials. RTs are not normally distributed but have a positive skew, i.e., the tail is longer on the right than the left side. The longer right tail of the distribution reflects the proportion of the slowest responses, while the remaining responses are in the normal part of the distribution. Shao et al. observed that updating ability was correlated with the length of the right tail of the distribution of both action and object naming (i.e., the slowest responses), while inhibiting ability was correlated with the normal part of the RT distribution of action naming and the tail of the distribution of object naming.

These findings suggest that both updating and inhibiting play important roles in picture naming but in different ways. Updating ability is reflected in individual differences in picture naming RT for the slowest responses, for both objects and actions. This result suggests that updating ability is especially taxed on the most demanding trials of picture naming. In contrast, inhibiting ability seems to be involved on most of the trials in action naming but only on the demanding trials in object naming. This may be due to the fact that action naming is generally more demanding than object naming, as reflected in longer mean RTs for the former. As mentioned, Shao et al. (2012) did not find a correlation between shifting ability and picture naming RT. However, this does not exclude the possibility that shifting ability is involved in forms of language production that are more complex than picture naming, especially when actual switching is required. To conclude, Shao et al. found evidence that updating and inhibiting contribute to the speed of picture naming, in particular when naming is highly demanding, as reflected in the long RTs.

Piai and Roelofs (2013) assessed object naming performance as part of a dual-task procedure, and found evidence that the engagement of executive control depends on processing demand. In contrast to Shao et al. (2012), they did find a correlation between updating ability and mean object naming RT. This result suggests that object naming taxes updating ability more in dual-task than in single-task performance, such that individual differences in this ability are reflected in the mean naming RTs.

To summarize, previous studies provided evidence for contributions of executive control to picture naming. To assess whether these findings generalize to more complex language performance, it is necessary to investigate whether each hypothesized component of executive control influences other forms of language production than picture naming. Moreover, it is important to assess whether shifting ability contributes to language production in situations that more explicitly engage this ability. The aim of the present study was to examine these issues by investigating the contributions of updating, inhibiting, and shifting to spoken phrase production in healthy adult participants.

Outline of the present study

We assessed phrase production performance using picture description and a picture-word interference procedure. First, we measured length, distractor, and switch effects in the picture description RTs, which were hypothesized to relate to updating, inhibiting, and shifting abilities, respectively. Second, for each participant we obtained scores on executive control tasks that measure verbal and nonverbal updating, nonverbal inhibiting, and nonverbal shifting abilities. We then tested for correlations between these executive ability scores and the magnitudes of the corresponding RT effects in the picture description task.

Participants described pictures of simple objects by producing noun phrases in Dutch. We used a set of only four pictures (i.e., a fork, a plate, a glass, and a bottle) to reduce variance due to differences in processing speed among pictures and words. The pictures were presented on the screen for only 250 ms. The brief presentation served to increase the demands on executive control. The small number of pictures and their brief presentation are somewhat uncommon features of our task meant to improve our assessment of the contributions of executive control. The pictures were presented in color (e.g., a black line-drawing of a fork in green color on a white computer screen) or without color (e.g., a black line-drawing of a fork in white on a white computer screen).

In response to the colored pictures, participants produced determiner-adjective-noun phrases, with the adjective referring to the color, henceforth the *long* phrases. In response to the white pictures, they produced determiner-noun phrases without the adjective, henceforth the *short* phrases. In one block of trials, the determiners were gender-marked *definite* articles, "de" (for nouns with common gender) or "het" (for nouns with neuter gender), and in another block of trials, the determiner was an *indefinite* article without gender-marking, "een". Thus, we examined not only the production of definite noun phrases, as has been done before (e.g., Roelofs, 2003, 2006; Schriefers, 1992, 1993; Schiller & Caramazza, 2003), but also the production of indefinite phrases, which has been neglected in previous research. In the determiner-adjective-noun phrases with the indefinite article, the adjective is inflected to mark the gender of the noun. For example, the adjective *groen* becomes "groen" for neuter nouns (e.g., "een groen bord", a green plate) and "groene" for common nouns (e.g., "een groene vork", a green fork). In contrast, with definite articles, the article but not the adjective is marked for grammatical gender (e.g., "het groene bord" and "de groene vork"). In planning determiner-adjective-noun phrases, speakers have to conceptually identify not only the pictured object but also its color, and they have to retrieve from long-term memory a corresponding noun and color adjective. Moreover, they have to retrieve the indefinite article and inflect the color adjective (in the indefinite-article blocks) or retrieve the appropriate gender-marked article (in definite-article blocks). Following this, a syntactic structure has to be computed (Levelt, 1989) or retrieved from memory (Vosse & Kempen, 2000), and the determiner, adjective, and noun have to be serially ordered. In contrast, in planning determiner-noun phrases, speakers have to conceptually identify the pictured object but not the color, retrieve a corresponding noun and definite or indefinite article, compute or retrieve a syntactic structure, and serially order the words. Conceptual preparation and syntactic encoding are followed by morphophonological and phonetic encoding, and finally, articulation (e.g., Levelt, 1989). Given that more information needs to be derived from the picture and manipulated in working memory for the long phrases as compared to the short phrases, we expected that updating ability would be more strongly engaged when producing the former. Consequently, the magnitude of the difference in RT between these phrase types, henceforth the *length effect*, is expected to reflect a speaker's updating ability (Korvorst, Roelofs, & Levelt, 2006; Meyer, Roelofs, & Levelt, 2003).

To assess the contribution of inhibiting ability, the pictures were combined with auditory distractor words, which could be congruent (e.g., the auditory distractor word "vork" combined with a picture of a fork) or incongruent (e.g., the auditory distractor word "bord" combined with a picture of a fork). We expected that inhibiting would be more strongly engaged with incongruent distractors than with congruent distractors and that the magnitude of the difference in RT between these distractor types, henceforth the *distractor effect*, would reflect a speaker's inhibiting ability. Note that the grammatical gender of the picture name and the incongruent distractor word may be the same or different, creating an additional source of interference, either at the level of the articles ("de" versus "het") or the inflection of the adjective (e.g., "groen" versus "groene"). The difference in RT between incongruent distractors with the same or different gender is referred to as the *gender congruency effect*.

As suggested by Schriefers, Meyer, and Levelt (1990) in a seminal article on the effect of spoken distractors in picture naming, there exists no good neutral baseline. For example, presenting a spoken word distractor will delay picture naming relative to a silence condition regardless of the relationship between picture and distractor simply because of the sound of the spoken distractor. However, presenting pink noise instead of using silence will suffer from the problem of comparing the effect of linguistic and non-linguistic distractors. Therefore, the psycholinguistic literature has settled on testing between different word conditions, such as semantically related versus unrelated, phonologically related versus unrelated, or incongruent (semantically related) versus congruent (identical), as is often done in the literature on Stroop-like effects (e.g., color-word Stroop, Eriksen flanker, or Simon, see

Piai, Roelofs, Acheson, & Takashima, 2013). We decided to use incongruent and congruent distractors, because this contrast typically yields the largest and most robust RT effect (e.g., Schriefers et al., 1990), which would increase the chance of finding a correlation with inhibiting ability. The incongruent-congruent contrast does not allow us to specifically relate the effect to any stage of word production (unlike semantic or phonological effects), but this was also not the aim of our study. Table 1 gives example materials for the length and distractors conditions for each of the grammatical genders and definiteness conditions.

Table 1: Example materials for the length (short, long) and distractor (congruent noun and gender, incongruent noun with congruent gender, incongruent noun with incongruent gender) conditions for each of the two grammatical genders (common, neuter) and definiteness conditions (definite, indefinite). English translations of the Dutch materials are between parentheses.

	Length		Distractor		
Gender	Short	Long	Congruent/ congruent	Incongruent/ congruent	Incongruent/ incongruent
			Definite article		
Common	de vork (the fork)	de groene vork (the green fork)	vork (fork)	fles (bottle)	bord (plate)
Neuter	het bord (the plate)	het groene bord (the green plate)	bord (plate)	glas (glass)	vork (fork)
			Indefinite article		
Common	een vork (a fork)	een groene vork (a green fork)	vork (fork)	fles (bottle)	bord (plate)
Neuter	een bord (a plate)	een groen bord (a green plate)	bord (plate)	glas (glass)	vork (fork)

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 white) could be followed by two long phrases (for pictures in color) or vice versa. A trial that repeats the previous phrase type (short preceded by short or long preceded by long) is referred to as a repeat trial, and a trial that does not repeat the previous phrase type (short preceded by long or long preceded by short) is referred to as a switch trial. Speakers may need to engage the shifting ability on switch trials to enable to production of a different phrase type. We expected that shifting would be more strongly engaged on switch than repeat trials and that the magnitude of the difference in RT between these trial types, henceforth the *shifting effect*, would reflect a speaker's shifting ability.

In addition, we measured participants' updating, inhibiting, and shifting abilities with standard tasks commonly used to assess executive control (Collette et al., 2005; Conway et al., 2005; Friedman et al., 2008; Miyake et al., 2000). It could be possible that there are linguistic updating processes that are partly independent from the nonverbal processes (e.g., Montgomery et al., 2010). Therefore, we used the operation-span and odd-one-out tasks (Conway et al., 2005) to assess verbal and nonverbal updating ability, respectively. Moreover, we used 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. Detailed descriptions of these tasks are given below in the Method section. We expected that individual differences in the scores for these executive control tasks would correlate with the corresponding effects in the picture description RTs. In particular, the operation-span and odd-one-out scores were expected to correlate with the length effect in RTs (both reflecting the updating ability), the stop-signal scores were expected to correlate with the distractor effect (both reflecting the inhibiting ability), and the scores on the shape-color switching task were expected to correlate with the RT switch effect (both reflecting the shifting ability).

Following Shao et al. (2012), we not only examined correlations of executive control scores with mean RTs but also with components of the underlying RT distribution by performing ex-Gaussian analyses. The ex-Gaussian function consists of a convolution of a Gaussian (i.e., normal) and an exponential distribution, which generally provides good fits to empirical RT distributions (e.g., Luce, 1986; Ratcliff, 1978). The analyses provide three parameters characterizing a distribution, called μ, σ, and τ. The μ and σ parameters reflect the mean and standard deviation of the Gaussian portion, and τ reflects the mean and standard deviation of the exponential portion. The mean of the whole distribution (i.e., the mean RT) equals the sum of μ and τ. Thus, ex-Gaussian analyses decompose mean RTs into two additive components, which characterize the normal part (μ) and the right tail (τ) of the underlying RT distribution.

Finally, following Shao et al. (2013), we performed delta-plot analyses to further examine the contribution of inhibiting. Previous research distinguished between nonselective and selective inhibition (Forstmann et al., 2008). Nonselective inhibition is involved in the suppression of any unwanted response (like in the stop-signal task or any distractor in the picture-word interference task), while selective inhibition is involved in the suppression of specific responses that compete for selection (like semantically related distractors in the picture-word interference task). A way to measure selective inhibition is by calculation of delta plots. Delta plots can be derived by rank ordering condition RTs and dividing them into quantiles (e.g., 20 percent bins). The distractor effect or "delta" is then determined for each quantile, that is, as a function of the relative speed of responding. Evidence suggests that selective inhibition builds up over time, so that the influence of inhibition is most strongly reflected in the slowest responses (e.g., Ridderinkhof, 2002; Van den Wildenberg et al., 2011). That is, better inhibitory ability is associated with smaller distractor effects for the slowest responses. This may be quantified by computing the slopes of the delta plots, that is, the difference between the deltas of consecutive quantiles divided by the difference in the corresponding quantile mean RTs. Previous research has suggested that better inhibiting ability is associated with shallower or negative-going slopes for the slowest responses, that is, the slopes of the slowest delta segments (e.g., Ridderinkhof, 2002; Van den Wildenberg et al., 2011).

Shao et al. (2013) obtained evidence that both selective and nonselective inhibition are involved in picture naming but in different ways. Participants had to name pictured objects (e.g., a fork) with superimposed written distractor words, which were semantically related (e.g., *knife*) or unrelated (e.g., *car*). Nonselective inhibiting ability, as indexed by scores for the stop-signal task, was correlated with the mean RT regardless of the type of word distractor (i.e., semantically related or unrelated) in picture naming. In contrast, selective inhibiting ability, as indexed by slopes of the slowest delta segment, was correlated with the magnitude of the semantic effect (i.e., the difference in RT between semantically related and unrelated distractors). Moreover, the selective and nonselective inhibiting measures were not correlated. This suggests that selective inhibiting is engaged to selectively suppress distractors that are semantically related (thereby reducing the magnitude of the semantic effect), whereas nonselective inhibiting is engaged to suppress any competing word, regardless of semantic relatedness (thereby reducing the mean RTs). In the present study, we used the stop-signal task to assess nonselective inhibiting ability and we performed delta-plot analyses to assess selective inhibiting ability.

Method

Participants

Forty native speakers of Dutch participated in the experiment (28 women and 12 men, mean age = 24.08 years, age range: 19 to 37 years). The participants were recruited via the Radboud University SONA system. They received 12.50 Euros or 1.5 credits for their participation.

Procedure and design

The participants signed the informed consent before the experimental session. Following standard practice in individual differences research, tasks and blocks within tasks were presented to all the participants in the exact same order to minimize any measurement error due to participant by order interaction (cf. Friedman et al., 2008; Miyake et al., 2000). First, they performed the picture description task, followed by the odd-one-out task, the stop-signal task, the operation-span task, and the shape-color switching task. After the experimental session, participants were debriefed and paid for their participation. An experimental session lasted about 1 hour and 15 minutes.

Picture-description task. In this task, participants had to describe a picture presented in the middle of a computer screen while trying to ignore a spoken distractor that was played via headphones. Each trial began with a fixation cross which remained on the screen for 700 ms, followed by the presentation of a spoken distractor and a picture simultaneously (i.e., with the same presentation onset). The picture remained on the screen for 250 ms followed by a blank screen for 2150 ms. Each picture was presented with a congruent distractor, an incongruent distractor with congruent gender, and an incongruent distractor with incongruent gender. Hence, each picture was pared with three different spoken distractors. Each spoken distractor was presented an equal number of times in the experiment. For each participant, the stimulus list was randomized using the program Mix (Van Casteren & Davis, 2006) with the restriction that stimuli were not repeated on consecutive trials. To focus on the influences of executive control and to reduce variance due to differences in processing speed among pictures and words, only a limited number of objects and colors were used. The set of stimuli consisted of four pictures, namely a bottle, a plate, a glass, and a fork, and four spoken distractors, which were the names of these objects. All spoken distractors were monosyllabic Dutch words: *fles* (*bottle*), *bord* (*plate*), *glas* (*glass*), and *vork* (*fork*). The words were all semantically related (like in the color-word Stroop task, e.g., Roelofs, 2003). The spoken words were recorded by a female native speaker of Dutch. The mean duration of the spoken distractor was 530 ms. All the participants ran through the experiment in the exact same order (cf. Friedman et al., 2008; Miyake et al., 2000). There were two practice blocks and eight experimental blocks of trials. Each experimental session began with two practice blocks. In the first practice block, participants had to describe all the pictures using noun phrases with a definite article and in the second practice block participants described all the pictures using phrases with an indefinite article. Next, in the experimental part, participants used definite phrases (definite condition) in four of the blocks and indefinite phrases (indefinite condition) in another four blocks. Participants always began with a definite article block followed by an indefinite article block. The four definite and four indefinite blocks of trials were alternated: definite, indefinite, definite, indefinite, etc. Before each experimental block, participant received information about the required type of noun phrase, definite or indefinite. Each experimental block consisted of 48 trials. In total there were 192 trials for the definite condition and 192 trials for the indefinite condition.

As mentioned earlier, the Dutch language distinguishes between common nouns, which take the article “de”, and neuter nouns, which take the article “het” as definite determiners. Two words, *glas* (*glass*) and *bord* (*plate*), were neuter-gender nouns, and the two other words, *vork* (*fork*) and *fles* (*bottle*), were common-gender nouns. The picture names and the spoken distractors could be either two identical nouns (congruent condition), two different nouns taking the same grammatical gender (incongruent noun with congruent gender condition), or two different nouns taking different genders (incongruent noun with incongruent gender condition). Each of these distractor conditions had the same number of trials. The pictures were either black-and-white drawings or colored drawings, either blue or green. The participants were instructed to produce determiner-noun phrases (e.g., “de vork” or “een vork”) when the presented picture was a black-and-white drawing (the short phrase condition). When the picture was presented in one of the two colors, the participants had to produce a phrase that included an article, a color adjective, and the name of the object (e.g., “de groene vork” or “een groene vork”, the long phrase condition). The number of trials for these conditions was the same. The pictures were presented such that the required phrase type changed every second trial. Thus, in the trial sequence, two black-and-white pictures were followed by two colored pictures, which were followed by two black-and-white pictures, etc. This designed allowed us to measure picture description RT on repeat and switch trials. The number of trials for the repeat and switch conditions was equal.

Odd-one-out task. The odd-one-out task measures nonverbal updating ability (Conway et al., 2005). The odd-one-out task consisted of 60 triples of drawings representing arbitrary shapes. For each triple, two shapes were identical and one was different. The three figures were presented on the computer screen and the participants were instructed to indicate by pressing one of three buttons which figure is different from the others (i.e., the odd-one-out). The left button denoted the left figure, the middle button denoted the middle figure, and the right button denoted the right figure. Moreover, the participants were told to remember the location of the odd-one-out figure on each trial. After a random number of trials (varying between two and six), the participants had to recall the location of all odd-one-out figures since the beginning of a set. A table with three columns was presented on the computer screen. Each column referred to the three locations and the rows referred to the trials. The participants indicated the recalled locations of the odd-one-out figures in the table, in the correct order, by sequentially pressing the corresponding buttons. This was followed by a next set of new figures.

Operation-span task. The operation-span task measures verbal updating ability (Conway et al., 2005). The operation-span task consisted of 60 mathematical operations and 60 Dutch words. Materials were presented on the computer screen. Each trial began with a fixation cross presented for 800 ms followed by a mathematical operation and a word presented in the middle of the screen (e.g., 12-4/2=3? Strand). The participants were instructed to read aloud the mathematical operation and the word. Next, the participants had to indicate by a button press whether the mathematical operation was correct. After a random number of trials (varying between two and six), participants had to recall all words presented since the beginning of a set. The instruction "write down" displayed on the screen indicated that a participant had to recall and write down all words in the correct order. This was followed by a new set of mathematical operations and words.

Stop-signal task. The stop-signal task measures nonverbal inhibiting ability (Verbruggen et al., 2008). The task consisted of 75% "go" trials and 25% "stop" trials. Each go trial began with a fixation point presented in the middle of the screen for 250 ms, followed by a target stimulus. The target stimulus was either a square or a circle. The participants were instructed to respond to the stimuli by pressing one button (labeled "?") when they saw a circle and another button (labelled "Z") when they saw a square. The stimuli remained on the screen until the participant responded but not longer than for 1250 ms. The participants were told to respond to the stimuli as quick and accurate as possible. On the stop trials also an auditory stimulus was presented. The auditory stimuli followed the visual stimuli. The participants were instructed to inhibit their response to the visual stimuli on the trials when the auditory stimuli were presented. First the auditory stimuli were presented 250 ms after onset of the visual stimuli (the stop-signal delay). After each successful stop trial, the stop-signal delay was increased with 50 ms, while after each unsuccessful stop trial the stop-signal delay was decreased with 50 ms. The task consisted of one practice and three experimental blocks. The practice block included 32 trials and each experimental block included 64 trials.

Shape-color switching task. The shape-color switching task measures nonverbal shifting ability (Miyake et al., 2000). The task consisted of visual stimuli presented on the computer screen. The stimuli were a square or a circle that could be either red or green. The participants were instructed to respond to the color of the stimuli when the figures were presented in the top of the screen, and to the shape of the stimuli when the figures were presented in the bottom of the screen. Response buttons were "↓" and "↑". The participants had to press "↓" as a response to the stimuli that were either red or a circle and they had to press "↑" as a response to the stimuli that were either green or a square. There were three practice blocks and three experimental blocks. In the first block, stimuli were presented only in the top of the screen, the color block. In the second block, stimuli were presented only in the bottom of the screen, the shape block. In the last block, stimuli were presented in clockwise rotation, beginning in the upper right quadrant of the screen, followed by the lower right quadrant, followed by the lower left quadrant, and the upper left quadrant. The shape and the color blocks consisted of 48 trials. The mixed block consisted of 128 trials.

Data analysis

Picture-description task. The data of four participants for this task were excluded from the analysis because they did not correctly follow the instructions. In total, the data of 36 subjects were included in the analysis. Responses were excluded from the analysis if the produced phrase did not match the correct phrase or when the response included any kind of disfluency or was not completed before the end of a trial. Mean RTs were calculated separately for the definite blocks and indefinite blocks. For each block, mean RTs were calculated for seven conditions: long phrase condition, short phrase condition, congruent condition, incongruent noun with congruent gender condition, incongruent noun with incongruent gender condition, repeat condition, and switch condition. Repeated measures ANOVAs were conducted to test for main effects and interactions between conditions. Four effects were defined: *definiteness* (definite vs. indefinite), *length* (short vs. long phrase), *distractor* (congruent vs. incongruent noun with congruent gender vs. incongruent noun with incongruent gender), and *switch* (repeat vs. switch trials).

Pearson correlations were computed between the scores for the executive control tasks and the three effects measured by the language production task (length, distractor, and switch). The length effect was calculated for each participant by subtracting the mean RT of the short phrase condition from the mean RT of the long phrase condition. The distractor effect was calculated by subtracting the mean RT of the congruent condition from the mean RT of the incongruent noun with congruent gender condition. Note that the incongruent noun with incongruent gender condition was not entered into the correlation analyses. Whereas the congruent condition and the incongruent noun with congruent gender condition differ in the congruency of the noun but not the grammatical gender (which is the same for picture name and distractor word), the grammatical gender differs between the congruent condition and the incongruent noun with incongruent gender condition. Thus, the latter contrast not only includes a difference in noun but also in grammatical gender, which complicates the interpretation of the effect. Therefore, the distractor effect that entered the correlation analyses concerned the difference in RT between the congruent condition and the incongruent noun with congruent gender condition. Finally, the switch effect was calculated by subtracting the mean RT of the repeat condition from the switch condition.

Odd-one-out task. Scores for the odd-one-out task were calculated following the guidelines of Conway et al. (2005). The score of one participant was excluded from the analysis because the accuracy in the odd-one-out task was below 85%. The number of correctly recalled locations of the odd figures in a set was calculated. The number of figures in a set varied between two and six. The participants received 1 point for each correctly recalled set. There were in total 15 sets. Thus, the total scores could range between 0 and 15. The score for each set was calculated as the proportion of the correctly recalled locations and the total number of locations to be recalled within the set. For example, correctly recalling the locations of two odd figures of a set of six figures was scored as 0.33 point, while correctly recalling the locations of two odd figures of a set of four figures was scored as 0.5 point. Higher total scores on the odd-one-out task indicate better (nonverbal) updating ability.

Operation-span task. Scores for the operation-span task were also calculated following the guidelines of Conway et al. (2005). The scores of two participants were excluded from the analysis as one of the participants had lower than 85%

accuracy for the mathematical operations and another participant did not correctly follow the instructions. The number of correctly recalled words for each set was calculated. The number of the words in each set varied between two and six. In total there were 15 sets. Participants could receive 1 point for each correctly recalled set, hence the total score could range between 0 and 15. The score for each set was calculated as the proportion of the correctly recalled words and the total number of words to be recalled within the set, similar to the scoring of the odd-one-out task. Higher total scores for the operation-span task indicate better updating ability.

Stop-signal task. Scores were calculated following the instructions of Verbruggen et al. (2008). The data of three participants were excluded from the analysis because of poor performance. The stop-signal reaction time (SSRT) was calculated for each participant. The SSRT is equal to the difference between the mean RT of all go-trials and the mean stop-signal delay. Shorter SSRTs indicate better inhibiting ability.

Shape-color switching task. Trials were categorized as errors and excluded from the analysis if a participant failed to respond correctly to the presented figure. Mean RTs for the switch trials from the third experimental block (trials from the upper left and the lower right quadrants of the screen) and for the repeat trials from the third experimental block (trials from the upper right and lower left quadrants of the screen) were calculated. The shifting score was obtained by subtracting the mean RT for the repeat trials from mean RT for the switch trials. Lower values indicate better shifting ability.

Correlation analyses. Pearson correlations were computed between the scores of the executive control tasks and the length, distractor, and switch effects in the picture description RTs as well as the overall mean RTs. Moreover, correlations were computed between the executive scores and the length, distractor, and switch effects in the three ex-Gaussian parameters (μ, σ and τ) as well as the mean values of the parameters across all conditions.

Ex-Gaussian analyses. For each participant, we estimated the values of the three ex-Gaussian parameters μ, σ, and τ for the RTs in each condition. The parameter values were estimated using the quantile method implemented in the QMPE software (Brown & Heathcote, 2003). We then computed the effects of length, distractor, and switch in these parameters. As explained earlier, the effects in the three ex-Gaussian parameters as well as the mean values of the parameters across all conditions were entered into the correlation analyses.

Delta-plot analyses. For each participant, the RTs of the congruent condition and the incongruent noun with congruent gender condition were rank-ordered and divided into quintiles (i.e., 20% bins), for each condition separately. For each quintile, mean RTs were calculated and the interference effect (delta) for each quintile was computed. Finally, the slopes of the lines that connect the delta values of consecutive quintiles were computed (Ridderinkhof, 2002). The literature suggests that the slope of the slowest delta segment (i.e., the slope of the line connecting the fourth and fifth quintiles) best indexes inhibition ability (e.g., Forstmann et al., 2008; Van den Wildenberg et al., 2010).

Results

Mean picture-description performance

The mean RTs and error rates for each of the conditions of the picture-description task are presented in Table 2. Mean RTs were longer for the definite than the indefinite phrases (definiteness effect), shorter for the short than the long phrases (length effect), shorter for the congruent condition than the incongruent noun with congruent gender condition (distractor noun effect), shorter for the incongruent noun with congruent gender condition than the incongruent noun with incongruent gender condition (gender congruency effect), and longer for switch than repeat trials (switch effect).

In tests of sphericity of the RT data, Mauchly's test of sphericity was significant for the interaction of definiteness and distractor, $\chi^2(2) = 6.52$, $p < .05$, which indicates a violation of the assumption of sphericity. Therefore, Greenhouse-Geisser estimates of sphericity were used to correct the degrees of freedom ($\varepsilon = .85$).

All main RT effects were found to be significant at $p < .001$. There was a main effect of definiteness: The participants responded faster in the indefinite than in the definite condition, $F(1, 35) = 145.39$, $MSE = 22801$, $\eta_p^2 = .81$. In addition, there was a main distractor effect, $F(2, 70) = 44.25$, $MSE = 9060$, $\eta_p^2 = .56$: Participants responded faster in the congruent noun condition than in the incongruent noun with congruent gender condition (distractor noun effect), $F(1, 35) = 44.85$, $MSE = 2085$, $\eta_p^2 = .56$, and slower in the incongruent noun with incongruent gender condition than in the incongruent noun with congruent gender condition (gender congruency effect), $F(1, 35) = 10.30$, $MSE = 1647$, $\eta_p^2 = .23$. There was also a main length effect: Participants responded faster in the short than long phrase condition $F(1, 35) = 29.81$, $MSE = 30827$, $\eta_p^2 = .46$. Finally, there was a main switch effect: The participants responded faster in the repeat than in the switch condition, $F(1, 35) = 24.57$, $MSE = 5682$, $\eta_p^2 = .41$.

Table 2: Mean reaction times (milliseconds) and percentage error (between parentheses) in the picture-description task

		Switch		
Distractor/Gender	Length	Repeat	Switch	*Total*
Definite article				
Congruent/congruent	Long	845 (12)	819 (10)	831 (11)
	Short	714 (5)	773 (3)	744 (4)
	Total	779 (8)	796 (7)	788 (7)
Incongruent/congruent	Long	891 (15)	877 (14)	884 (14)
	Short	778 (6)	838 (5)	808 (5)
	Total	834 (10)	857 (10)	846 (10)
Incongruent/incongruent	Long	935 (21)	934 (19)	934 (20)
	Short	808 (12)	876 (9)	842 (10)
	Total	871 (17)	905 (14)	888 (15)
Total	Long	890 (16)	876 (14)	883 (15)
	Short	767 (6)	829 (7)	798 (6)
	Total	828 (11)	853 (10)	840 (10)
Indefinite article				
Congruent/congruent	Long	728 (10)	701 (8)	714 (9)
	Short	629 (2)	690 (3)	660 (2)
	Total	678 (6)	696 (5)	687 (6)
Incongruent/congruent	Long	739 (14)	760 (13)	750 (13)
	Short	677 (4)	746 (5)	712 (4)
	Total	708 (9)	753 (9)	731 (9)
Incongruent/incongruent	Long	768 (14)	740 (14)	754 (14)
	Short	680 (5)	741 (8)	710 (6)
	Total	724 (9)	740 (11)	732 (10)
Total	Long	745 (13)	734 (11)	739 (12)
	Short	662 (3)	726 (5)	694 (4)
	Total	703 (8)	730 (8)	717(8)

Overall				
Congruent/congruent	Long	786 (11)	760 (9)	773 (10)
	Short	672 (3)	732 (3)	702 (3)
	Total	729 (7)	746 (6)	737 (7)
Incongruent/congruent	Long	815 (14)	819 (13)	817 (14)
	Short	728 (4)	792 (5)	760 (5)
	Total	771 (9)	805 (9)	788 (9)
Incongruent/incongruent	Long	851 (18)	837 (17)	844 (17)
	Short	744 (8)	809 (8)	776 (8)
	Total	797 (13)	823 (13)	810 (13)
Total	Long	817 (14)	805 (13)	811 (14)
	Short	714 (5)	777 (5)	746 (5)
	Total	766 (10)	791 (9)	779 (10)

Additionally, we found three significant interactions. There was an interaction between definiteness and distractor, $F(1.7, 59.6) = 11.8$, $MSE = 70160$, $p < .001$, $\eta_p^2 = .25$. As Figure 1 shows, this interaction occurred because the incongruent distractors yielded a difference in RT between the incongruent- and congruent-gender conditions for the definite phrases but not for the indefinite phrases. Moreover, there was an interaction between definiteness and length, $F(1, 35) = 23.94$, $MSE = 86108$, $p < .001$, $\eta_p^2 = .41$. Figure 2 shows that this interaction occurred because the length effect was larger for the definite than the indefinite phrases. Finally, there was an interaction between length and switch, $F(1, 35) = 33.9$, $MSE = 304638$, $p < .001$, $\eta_p^2 = .49$. Figure 3 shows that this interaction occurred because the switch effect was present for the short phrases, $t = 8.79$, $p < .001$ but not the long phrases, $t = -1.192$, $p = .24$.

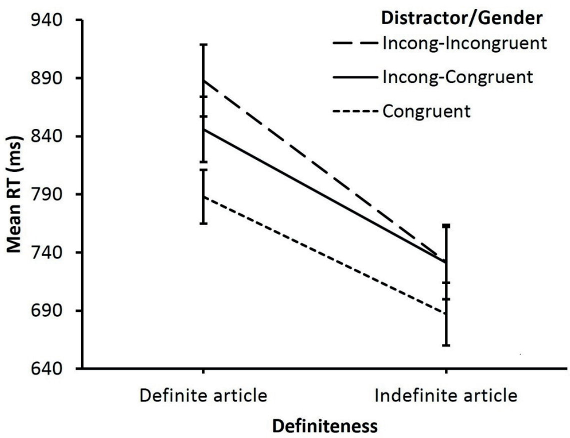

Figure 1: Mean response time (RT) for the picture descriptions per distractor condition (congruent noun/congruent gender, incongruent noun/congruent gender, incongruent noun/congruent gender) and definiteness condition (definite, indefinite). The error bars indicate one standard error.

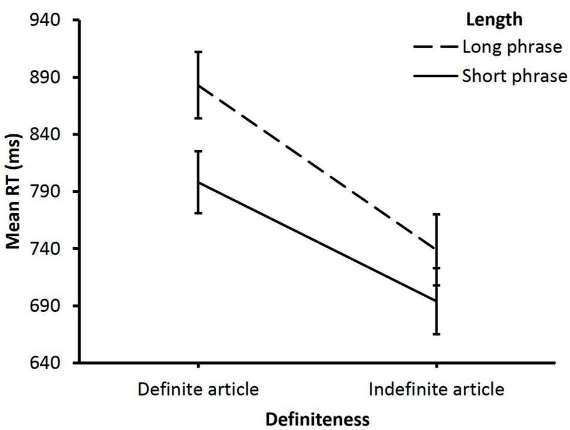

Figure 2: Mean response time (RT) for the picture descriptions per phrase type (long, short) and definiteness condition (definite, indefinite). The error bars indicate one standard error.

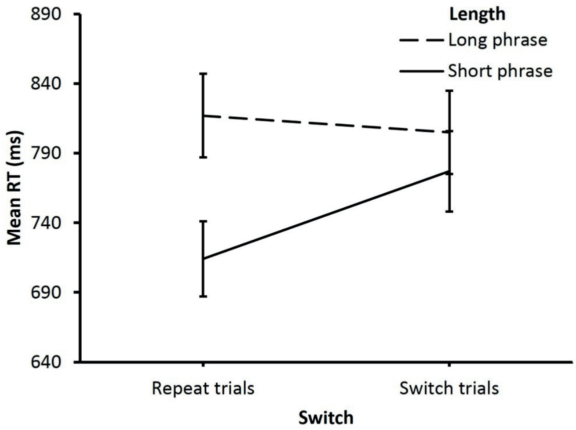

Figure 3: Mean response time (RT) for the picture descriptions per length condition (short, long) on repeat and switch trials. The error bars indicate one standard error.

Correlation analyses

We analyzed the correlations among the scores of the executive control tasks (i.e., operation span, odd-one-out, stop signal, and shape-color switching), the mean picture description RTs, and the three effects in the RTs (i.e., length, distractor, and switch). Excluded data points were coded as missing values. Moreover, the score of one participant on the operation-span task was identified as an outlier using the Mahalanobis' distance (Conway et al., 2005) and excluded from the analysis. The correlations are presented in Tables 3 and 4.

Table 3: Correlations among the scores for the executive control tasks. Odd-one-out and operation span are assumed to index updating ability, stop signal is assumed to index inhibiting ability and shape-color switching is assumed to index shifting ability.

	Odd-one-out	Operation span	Stop signal
Operation span	.582**		
Stop signal	-.212	-.014	
Shape-color switching	-.217	-.098	.085

Note: ** *p* < .01

Table 3 presents the correlations among the scores on the executive control tasks. The table shows that there were no significant correlations except between the scores for the operation-span and odd-one-out tasks. Table 4 presents the correlations among the scores for the executive control tasks, the mean picture description RTs, and the three effects in the RTs. The table shows that the operation-span and odd-one-out scores correlated with the overall mean RT, and additionally, the operation-span scores correlated with the length effect in the RTs. Moreover, the stop-signal scores correlated with the distractor effect. For the shape-color switching scores no significant correlations were obtained.

Table 4: Correlations among the scores for the executive control tasks and the mean reaction times and effects in the picture-description task. The correlations for participants with scores on all executive control tasks are given between parentheses.

	Length effect	Distractor effect	Switch effect	Total RT
Odd-one-out	.085	-.276	.046	-.510**
	(-.033)	(-.214)	(-.049)	(-.418*)
Operation span	-.353*	-.089	.057	-.307*
	(-.336*)	(-.092)	(.047)	(-.338*)
Stop signal	-.079	.451**	.121	.186
	(-.141)	(.402*)	(.153)	(.167)
Shape-color switching	.112	-.031	.031	.148
	(-.142)	(.056)	(.021)	(.067)

*Note:*** $p < .01$ * $p < .05$

In the correlation analyses, we did not include an equal number of participants for each test. Instead, we included the score of a participant if it met the criterion of a test (i.e., operation span task, odd-one-out task, stop-signal task, and color-shape task) regardless of whether the participant met the criteria of all the other tests. For instance, if a participant had to be excluded from the stop-signal task because the score did not qualify according to the criteria of this test (e.g., too many errors), the scores of this participant on other tests were still included if these scores passed the criteria of those tests. If we exclude a participant's scores on all of the tests because the scores of one test did not pass the criteria of that test, the number of participants entering the correlation analyses would considerably decrease. This would likely result in weaker correlations. Still, to test whether the reported results were due to the unequal number of participants on the tests, we ran our analysis with an equal number of participants on all tests (i.e., using the general exclusion criterion) and thus a lower total number of participants. These correlations are presented between parentheses in Table 4. As can be seen, the correlations were overall weaker but still significant. Thus, the pattern of correlations is the same with unequal and equal numbers of participants for the executive control tasks.

Ex-Gaussian analyses

We also analyzed the correlations between the scores for the four executive control tasks and the values of the three ex-Gaussian parameters across conditions. Moreover, we analyzed the correlations between the executive control scores and the length, distractor, and switch effects in the three ex-Gaussian parameters characterizing the RT distributions.

We found correlations between the scores on the operation-span and odd-one-out tasks and the μ of the distribution of RTs across all conditions, $r = -.407$, $p < .01$, and $r = -.509$, $p < .001$, respectively. Moreover, we found a positive correlation between the scores on the shape-color switching task and the switch effect in μ, $r = .316$, $p < .05$, while the correlation was negative for the switch effect in the τ parameter, $r = -.36$, $p < .05$. The negative correlation between the scores on the shape-color switching task and the τ parameter was surprising. We address this finding in the Discussion section.

Delta-plot analyses

We analyzed the correlations among the slope of slowest delta segment, the scores on the stop-signal task, and the mean distractor effect in the RTs.

The stop-signal scores correlated with the mean distractor effect in the RTs, $r = .451$, $p < .01$. Moreover, we found a correlation between the slopes of the slowest delta segment (i.e., the final slope) and the distractor effect, $r = .294$, $p < .01$. Figure 4 shows the corresponding scatter plots. There was no correlation between the stop-signal scores and the slopes of the slowest delta segment, $r = .073$, $p = .34$.

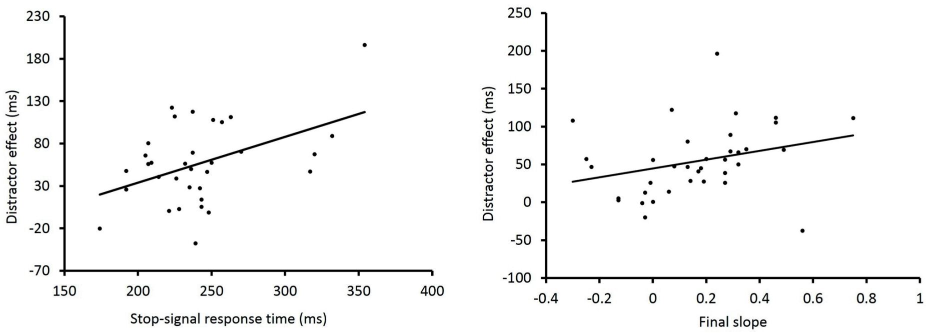

Figure 4: Scatter plots of the relationship between (a) the distractor effect and the stop-signal response time and (b) the distractor effect and the slope of the slowest delta segment.

Discussion

The present study examined the influence of executive control on language production. More specifically, we investigated how individual differences in updating, inhibiting, and shifting abilities influence phrase production. The language task used in this study allowed us to measure the involvement of all three components of executive control proposed by Miyake et al. (2000). We measured how fast a speaker produces a phrase in higher-demand updating, inhibiting, and shifting conditions as compared to lower-demand conditions. We argued that executive control will be more strongly engaged in more demanding conditions, hence differences in the speed of performance between higher- and lower-demand conditions will reflect differential engagement of the speakers' updating, inhibiting, and shifting abilities. We found that participants responded faster in the lower- than the higher-demand conditions, as reflected in the mean RTs. More specifically, speakers described pictures faster in the short- than long-phrase condition, faster in the congruent than incongruent distractor conditions, and faster in the repeat than switch condition. These findings suggest that an increase in executive demand has consequences for the speed of language production.

On the long phrase trials, speakers had to process and maintain in working memory the relevant information for three components of the phrase, namely the determiner, adjective, and noun, whereas on short phrase trials, this was required only for two components, namely the determiner and noun. This difference in processing demand was reflected in the RTs as the length effect. Moreover, individual differences in verbal updating scores, obtained by the operation-span task, correlated with the magnitude of the length effect in the RTs. Better updating scores were associated with smaller length effects. Both verbal and nonverbal updating scores (the latter obtained by the odd-one-out task) correlated with overall mean RTs. Better updating scores were associated with shorter RTs. These results suggest that the speed of phrase production is influenced by the updating ability of the speaker.

On incongruent distractor trials, speakers had to overcome interference of incongruent distractor words, whereas on congruent distractor trials, there was no such interference. This difference in processing demand was reflected in the RTs as the distractor effect. Moreover, individual differences in inhibiting scores, as obtained by the stop-signal task, correlated with the magnitude of the distractor effect in the RTs. Better inhibiting scores were associated with smaller distractor effects. These results suggest that phrase production is influenced by inhibiting ability.

On repeat trials, the length of the phrase was the same as on the previous trial, whereas the length of the phrases differed on switch trials. Thus, speakers could keep the previous task demands in working memory (e.g., to maintain and process information for two or three phrase components) on repeat trials, whereas they had to change the task demands on switch trials. This difference in processing demand was reflected in the RTs as the switch effect. In addition, there was an interaction with phrase length: The switch effect in RTs was present for the short phrases but not for the long ones. Individual differences in shifting scores, as obtained by the shape-color switching task, did not correlate with the magnitude of the switch effect in the mean RTs. However, analyses of the shape of the RT distributions revealed that individual differences in shifting scores correlated positively with the switch effect in the normal part of the distribution and negatively with the switch effect in the tail. Thus, better shape-color shifting scores were associated with a smaller switch effect on most of the picture-description trials but with a larger switch effect on the abnormally slow trials. These results suggest that phrase production is influenced by the shifting ability.

To summarize, we observed length, distractor, and switch effects in mean RTs and/or RT distributional components in noun phrase production. The magnitude of these length, distractor, and switch effects correlated with individual differences in updating, inhibiting, and shifting scores, respectively. Thus, all three components of executive control distinguished by Miyake et al. (2000) appear to influence language production. Our findings are in agreement with previous studies that observed an influence of updating and inhibiting ability on picture naming (Piai & Roelofs, 2013; Shao et al., 2012). The present study not only shows that updating and inhibiting ability may have an influence on more complex forms of language production than picture naming, namely phrase production, but also shows a novel influence of shifting ability. In the remainder of the manuscript, we discuss how the present findings relate to previous results in the literature and what they imply for the role of executive control in language production.

Psycholinguistic findings

The aim of the present study was to examine the influence of executive control on noun phrase production. To reduce error variance due to differences in processing speed among pictures and words, only a limited number of objects (four) and colors (two) were used in the present study. In contrast, previous investigations of phrase production in the literature used larger numbers of items. For example, in a seminal study of noun phrase production, Schriefers (1992) used 32 pictures and four colors. Nevertheless, the present study replicated a number of basic psycholinguistic findings in the literature, including the effect of congruency of grammatical gender between picture name and distractor word, and the interaction between definiteness and gender congruency. We briefly discuss these findings in turn, starting with the basic effect of definiteness.

We observed that the picture description RTs were shorter for indefinite phrases than for definite phrases. For both phrase types, the grammatical gender of the noun needs to be processed. However, for definite phrases, the grammatical gender determines the article (*de* vs. *het*), whereas for indefinite phrases the gender determines the inflection of the adjective (e.g., *groene* vs. *groen*). In the production of indefinite phrases, inflectional encoding of the adjective may occur while the speaker is articulating the indefinite article (*een*, which is the same on all indefinite trials), whereas the definite article (*de* or *het*) needs to be encoded before articulation onset for the definite phrases. This factor may explain why articulation onset is somewhat later for definite phrases. However, although the definite and indefinite blocks of trials were alternated in the experiment (i.e., definite, indefinite, definite, indefinite, etc.), all participants received the blocks in the same order (cf. Friedman et al., 2008; Miyake et al., 2000), always starting with a definite block of trials. Thus, in performing the first indefinite block, participants had already responded to the pictures by producing definite phrases. Consequently, indefinite blocks may have been associated with a greater amount of practice with the pictures than definite blocks, yielding shorter RTs for the indefinite than the definite condition. Thus, it remains possible that the finding of a shorter mean RT for the indefinite than the definite condition is fully or partly due to a differential amount of practice.

We also observed a gender congruency effect, replicating Schriefers (1993), Schriefers and Teruel (2000), Schiller and Caramazza (2003), La Heij, Mak, Sander, and Willeboordse (1998), and Van Berkum (1997), among others. Picture description RTs were shorter when the incongruent distractor word had the same grammatical gender as the picture name compared to a different gender. This gender congruency effect was obtained for the definite phrases but not for the indefinite phrases. This suggests that the gender congruency effect arose in selecting the appropriate article, which involved a choice for the definite phrases (between *de* or *het*) but not for the indefinite phrases (always *een*). Schiller and Caramazza (2003) obtained a similar finding for the production of noun phrases in Dutch and German. Participants had to refer to one or two pictured objects by producing singular or plural noun phrases. For the singular phrases, the article is gender-marked (*de* or *het* in Dutch), but for plural phrases it is not (i.e., *de* in Dutch regardless of grammatical gender). A gender congruency effect was obtained for the singular but not for the plural phrases, suggesting that the congruency effect arises in the selection of the article.

To conclude, although fewer pictures and colors were used in the present study than in previous studies in the literature, we replicated basic psycholinguistic findings. Thus, the influences of executive control on noun phrase production in the present study were obtained in the context of a replication of basic psycholinguistic findings.

Updating ability and language production

We found that the length effect in phrase production RTs correlated with scores on the operation-span task but not with those on the odd-one-out task. Several studies in the literature suggest that the operation-span and odd-one-out tasks both measure updating ability (Conway et al., 2005), whereas other studies make a distinction between verbal and nonverbal updating (e.g., Montgomery et al., 2010). We found that speakers with better verbal updating scores had a smaller length effect in the picture description RTs, whereas no such correlation was found with nonverbal updating scores. Thus, better verbal updating ability in particular may help to process and maintain a larger amount of information during language production. Moreover, both verbal and nonverbal updating scores correlated with the mean RTs across all conditions. This finding corresponds to the observations of Shao et al. (2012) and Piai and Roelofs (2013), showing that verbal updating scores correlate with picture naming RT. In line with the present study, speakers with better verbal updating scores were faster to name pictures in those previous studies. We not only replicated this correlation between verbal updating scores and RT for the production of noun phrases, but also observed that this correlation is obtained for both verbal and nonverbal updating scores.

It is not clear why verbal but not nonverbal updating scores correlated with the length effect in the RTs, whereas both scores correlated with overall mean RT. This difference in correlation pattern may be further investigated in future research. Regardless, the key point here is that our results indicate that updating ability influences phrase production.

We also found correlations between the scores of both the odd-one-out and operation-span tasks and the mean of the normal part of the RT distribution (i.e., the μ parameter of the ex-Gaussian distribution) across all conditions. As discussed before, this μ parameter represents the majority of the trials making up the distribution. These findings suggest that verbal and nonverbal updating abilities influence the speed of phrase production on a regular basis. Speakers with better updating scores were able to describe the pictures faster on most of the trials. In contrast, Shao et al. (2012) found that the (verbal) updating scores correlated with the τ parameter of the RT distribution of picture naming. The τ parameter represents the right tail of the RT distribution, made up by the abnormally slow responses, suggesting that, in picture naming, updating is reflected only in the slowest responses. In contrast, in the present study we found that updating was related to the normal part rather than the tail of the RT distribution. The phrase production task used in our study is more complex than picture naming. In more demanding situations like phrase production, speakers need to plan and process more information. Therefore, updating ability may be more regularly engaged in picture description requiring phrase production than it is in picture naming involving only single word production. Consequently, individual differences in updating ability are reflected in the normal part of the RT distribution in phrase production but only in the distribution tail in picture naming, as empirically observed.

To summarize, we found that both verbal and nonverbal updating abilities influenced the overall speed of phrase production. Individuals with better updating ability produced the phrases faster on most of the trials. Moreover, we observed that better verbal updating ability was associated with a smaller magnitude of the length effect. Speakers with better updating ability had a smaller difference in RT between the long and small phrases. These results provide evidence that updating ability is important for phrase production.

Inhibiting ability and language production

We found a correlation between the scores for the stop-signal task and the distractor effect in the picture description RTs. Individuals with better inhibiting scores had smaller distractor effects in the RTs. Thus, inhibiting ability may influence how well speakers can overcome interference from irrelevant spoken information during phrase production. It is generally assumed that a picture of an object not only activates its name in lexical memory but also, to a lesser extent, the names of semantically related objects (e.g., Levelt et al., 1999; Piai et al., 2014; Roelofs, 1992, 2003). For example, a picture of a fork not only activates the word *fork* but also competing words such as *plate*, *bottle*, and *glass*. An incongruent spoken distractor (e.g., *plate*) will boost the activation of one of those competitors, whereas a congruent distractor will activate the picture name. The present results suggest that speakers with better inhibiting abilities are able to suppress the competitors better than speakers with poorer inhibiting abilities.

Similar to Shao et al. (2012), we did not find a correlation between the updating and inhibiting scores. Moreover, updating scores were correlated with the length effect in RTs, whereas the inhibiting scores were correlated with the distractor effect. As suggested by Miyake et al. (2000), inhibiting and updating abilities are separable components of executive control. Our data suggest that, at least to some extent, the influences of updating and inhibiting abilities on language production are also separable.

In addition, we investigated what kind of inhibition influences language production. We obtained evidence suggesting that both selective and nonselective inhibition are involved. First, we found a correlation between the magnitude of the distractor effect in the mean picture description RTs and the scores on the stop-signal task, which are taken to index nonselective inhibiting ability (Forstmann et al., 2008). Second, we found a correlation between the magnitude of the distractor effect in the mean picture description RTs and the slopes of the slowest delta segment, which are taken to index selective inhibiting ability (Forstmann et al., 2008). We did not find a correlation between the scores on the stop-signal task and the slopes of the slowest delta segment, which suggests that these measures index separable kinds of inhibiting abilities (i.e., nonselective and selective).

Whereas Shao et al. (2012) found a correlation between the scores on the stop-signal task and picture naming RT, we did not observe such a correlation. In the study of Shao et al., no distractors were presented. Thus, the inhibiting ability influenced the degree to which competitors activated by the picture affected the naming RT. In the present study, a congruent or incongruent spoken distractor was presented on all trials, which dominated the competition on each trial. Consequently, the influence of inhibiting ability was reflected in the correlation with the magnitude of the distractor effect rather than the picture description RT per se.

To summarize, we obtained evidence for the involvement of both selective and nonselective inhibiting in phrase production. Our findings suggest that speakers with better selective as well as nonselective inhibiting abilities had smaller distractor effects in the picture description RTs. These results provide evidence that inhibiting ability is important for phrase production.

Shifting ability and language production

We did not obtain a correlation between shifting scores and the magnitude of the switch effect in the picture description RTs. However, RT distribution analyses revealed that shifting scores correlated positively with the switch effect in the normal part of the distribution and negatively with the switch effect in the distribution tail. Thus, better shifting scores were associated with a smaller switch effect on most of the trials but with a larger switch effect on the abnormally slow trials. Similar to the findings of Shao et al. (2012) for picture naming, we did not find a correlation between shifting scores and the overall mean picture description RTs. However, the role of shifting ability in simple picture naming is unclear, whereas it is much clearer in a situation involving actual switching, such as in the present study. This explains why we did obtain an influence of shifting ability, whereas Shao et al. did not.

We found a positive correlation between the shifting scores and the magnitude of the switch effect in the normal part of the RT distribution and a negative correlation with the switch effect in the tail. These opposite correlations explain why no overall correlation was found for the switch effect in the mean RT. The positive correlation between the shifting scores and the switch effect in the normal part of the distribution is as expected. Speakers with better shifting ability tend to have smaller switch effects on most of the trials. However, the negative correlation between the shifting scores and the switch effect in the tail of the distribution is unexpected. It implies that speakers with better shifting ability tend to have larger rather than smaller switch effects on the trials associated with long responses. This surprising finding may be due to the following. Participants had a limited amount of time to complete each trial. On trials that were for some reason difficult (for instance, because of a lapse of attention), speakers with poorer shifting ability might not have been able to complete the noun phrase in time, resulting in an error rather than a very slow response. In contrast, speakers with better shifting ability might have been able to complete the noun phrase in time, resulting in a very slow response rather than an error. As a consequence, the magnitude of the switch effect in the slowest responses may be larger for speakers with better as compared to poorer shifting ability, as we observed.

We suggest that speakers with better shifting ability would tend to be able to complete the phrase in time on trials that were for some reason difficult (the slowest trials making up the tail of the RT distribution), whereas speakers with poorer shifting ability would not tend to complete a correct phrase in time on those difficult trials. This would result in a larger magnitude of the switch effect in the slowest responses (i.e., the τ parameter) for speakers with better shifting ability. Thus, speakers with poorer shifting ability are expected to have more time-out errors on switch trials, predicting a positive correlation between the shifting ability as measured by shape-color task and the switch effect on time-out errors. We calculated the difference in the number of time-out errors between switch and repeat trials and we found that it correlated positively with the scores on the shape-color task, $r = .299$, $p < .05$. This suggests that subjects with poorer updating ability had indeed more time-out errors on switch than repeat trials when compared with subjects with better updating ability. For subjects making time-out errors, we assessed the correlation between the shape-color task scores and the switch effect in τ, and found a significant negative correlation, $r = -.612$, $p < .05$. Thus, poor shifting ability leads to a larger switch effect on time-out errors and a smaller switch effect in τ. This supports our conjecture that on difficult trials, speakers with better shifting ability are able to complete phrases in time, whereas speakers with poorer shifting ability are not.

We obtained an interaction between switching and length: The switch effect in mean RTs was obtained for short phrases but not for long phrases. This observation corresponds to the asymmetry in switch costs that is often obtained in task switching. For example, in switching between Stroop color naming and word reading, a switch effect is obtained for the (faster) word reading task but not for the (slower) color naming task (e.g., Allport & Wylie, 1999, 2000; Gilbert & Shallice, 2002). Similarly, in the present study, a switch effect was obtained for the (faster) short phrase production but not for the (slower) long phrase production. According to Allport and Wylie (1999, 2000), the switch effect is caused by task-set inertia: The irrelevant task set of the previous trial is still active on the current trial and needs to be actively disengaged. Asymmetrical switch effects may occur when the disengagement takes longer for one task than the another because of differential positive or negative priming of task set. For example, word reading is faster than color naming. Therefore, to prevent inadvertent word reading responses on Stroop color naming trials, the task set of the word reading task may be inhibited and the task set of color naming may be enhanced. In contrast, on word reading trials, inhibition of color naming and enhancement of word reading is not needed. As a consequence, disengagement from the previous task set will take much longer in switching to word reading than to color naming. Switching to word reading will be delayed because of positive priming of task set (i.e., previous enhancement of the color naming task), negative priming of task set (i.e., previous inhibition of the word reading task), or both.

In the present study, picture description RTs were shorter for the short than the long phrases. Colored pictures (e.g., a green fork) allowed both long-phrase responses (“de groene vork”) as well as short-phrase responses (“de vork”), whereas the noncolored pictures allowed for short-phrase responses only (i.e., “de groene vork” cannot be produced in response to a fork in white color). Therefore, to prevent the inadvertent production of short phrases in response to colored pictures, the task set for producing short phrases may be inhibited and the task set of producing long phrases may be enhanced. In contrast, on trials with noncolored pictures requiring a short phrase, inhibition of long phrases or enhancement of short phrases is not needed (because the pictures only allow a short-phrase response). As a consequence, disengagement from the previous task set will take much longer in switching to a short phrase than to a long phrase, as we observed. Switching to the production of a short phrase will be delayed because of positive priming of task set (i.e., previous enhancement of the task set for producing a long phrase), negative priming of task set (i.e., previous inhibition of the task set for producing a short phrase), or both.

The switching between phrase types is assumed to engage a shifting ability that is domain general, as is generally assumed in the executive control literature (e.g., Miyake et al., 2000). It now seems generally accepted in the task switching literature that asymmetrical switch costs are due to differential task-set inertia (Koch, Gade, Schuch, & Philipp, 2010), as originally proposed by Allport and colleagues (e.g., Allport & Wylie, 1999, 2000). This idea is also accepted by Monsell and colleagues (Yeung & Monsell, 2003), who originally proposed an alternative account. Moreover, also in the bilingual literature, language switching is assumed to engage a domain-general shifting ability (e.g., Abutalebi & Green, 2007). The task-set inertia idea seems to be generally accepted as an account of asymmetrical language switch costs (e.g., Koch et al., 2010, for a review), following the seminal proposal by Meuter and Allport (1999).

To conclude, the interaction between switch and length effects in the RTs in the present study is in line with previous findings obtained for switching between tasks of different strengths. The present interaction may receive an analogous explanation in terms of task set inertia (positive or negative priming of the previous task set), which may be different for the production of short and long phrases.

Conclusion

The goal of the present study was to examine whether the updating, inhibiting, and shifting abilities underlying executive control influence spoken noun-phrase production. We obtained evidence that all three executive abilities influence noun phrase production, and that they contribute to varying extents and in different ways.


LANGUAGE
PRODUCTION
UPDATING
SHIFTING
INHIBITING

CHAPTER 3

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

This chapter appeared as: Sikora, K., Roelofs, A., & Hermans, D. (2016). Electrophysiology of executive control in spoken noun-phrase production: Dynamics of updating, inhibiting, and shifting. *Neuropsychologia, 84*, 44-53.

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.

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. 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. Then, we describe our experimental procedure, which consisted of overt noun-phrase production to describe pictures and a picture-word interference paradigm. 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. Finally, we discuss what our electrophysiological findings reveal about the dynamics of executive control in noun-phrase production.

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 *switching 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 study was to replicate the behavioral observation of an asymmetric switch cost and to assess its electrophysiological manifestation.

ERP manifestations of updating, inhibiting, and shifting

Although previous behavioral studies have shown that updating, inhibiting, and shifting determine the RT of picture naming and description, there is a lack of evidence on the electrophysiological basis and dynamics of these abilities in language production. Previous research has identified electrophysiological correlates of executive control (e.g., Brydges, Fox, Reid, & Anderson, 2014; Folstein & Van Petten, 2008; Jackson et al., 2001; Kok, 2001; Polich & Kok, 1995; Polich, 2007). More specifically, the N200 and P300 components of the ERP have been studied extensively in relation to executive functions. However, these studies typically used rather simple manual tasks like oddball, Eriksen flanker, and Simon, or simple picture naming. Moreover, the studies typically concentrated on one executive function at a time, like updating, inhibiting, or shifting, but did not examine all three functions simultaneously using a single design. Furthermore, it has remained unclear how the N200 and P300 components of the ERP reflect the updating, inhibiting, and shifting abilities in a more complex task like phrase production.

The N200 component of the ERP is a negative-going deflection observed approximately 200-350 ms after stimulus onset, although the time window can vary depending on several factors, including characteristics of the stimuli, task, and participants (e.g., Folstein & Van Petten, 2008). The N200 can be subdivided into anterior and posterior subcomponents (e.g., Folstein & Van Petten, 2008; Verhoef, Roelofs, & Chwilla, 2010). The anterior N200 typically has a maximal amplitude at frontocentral electrode sides (i.e., Fz and Cz). Anterior N200 modulations have been found in various tasks involving inhibitory control such as the go/no-go task (e.g., Jodo & Kayama, 1992; Schmitt, Münte, & Kutas, 2000), the flanker task (e.g., Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kopp, Rist, & Mattler, 1996), and the stop-signal task (e.g., Schmajuk, Liotti, Busse, & Woldorff, 2006). A larger N200 amplitude has been associated with greater inhibitory demand. The anterior N200 has been linked also to inhibition in language switching (e.g., Jackson et al., 2001; Verhoef, Roelofs & Chwilla, 2009).

Moreover, Verhoef et al. (2010) obtained evidence that switching between languages is also reflected in the posterior N200, which typically has a maximal amplitude at centroparietal electrode sides (i.e., Cz and Pz). In testing bilingually unbalanced participants, Verhoef et al. found switch costs in the posterior N200 for the second language (L2) but not for the first language (L1). This difference in modulation of the posterior N200 was taken to reflect differential difficulty of disengagement from the previous language. Presumably, in unbalanced bilinguals, disengaging the weaker L2 is easier than disengaging the stronger L1. Consequently, the posterior N200 may reflect an effect for L2 switch trials requiring disengagement of the stronger L1, but not for L1 switch trials requiring disengagement of the weaker L2. Note that this account assumes that there was no differential inhibition of languages, otherwise the switch effect in the posterior N200 should have been obtained for L1 rather than L2 (i.e., switching to L1 would have required overcoming previous inhibition). In line with this assumption, the amplitude of the anterior N200 did not differ between languages in the study of

Verhoef et al. We are not aware of other studies testing for a switching effect in the posterior N200. The present study further examined this effect.

The P300 component of the ERP is a positive-going deflection observed approximately 200-500 ms after stimulus onset, although the time window can vary depending on several factors, including characteristics of the stimuli, task, and participants (e.g., Kok, 2001; Polich & Kok, 1995; Polich, 2007). The P300 can be divided into two subcomponents: P3a and P3b. The P3a has a central peak at the scalp and seems to reflect involuntary shifts or allocation of perceptual attention. For instance, the P3a is elicited by infrequent distractor stimuli in an oddball task. In the oddball task, participants are presented with a series of frequent standard stimuli and infrequent target and distractor stimuli, whereby a response is required only for the targets. In contrast to the P3a, the P3b has a more central-parietal distribution and is associated with the voluntary allocation of attention and updating of working memory. The P3b occurs in response to infrequent targets in the oddball task but also in tasks requiring more complex types of information processing, such as N-back (e.g., Evans, Selinger, & Pollak, 2011; Watter, Geffen, & Geffen, 2001) and dual-task performance (e.g., Kramer, Sirevaag, & Braune, 1987; Strayer & Drews, 2007; Wickens, Kramer, Vanasse, & Donchin, 1983). Previous research showed that the amplitude of the P3b component is modulated by the relative demands on the updating of working memory. More difficult task conditions elicit a smaller P3b amplitude than less demanding conditions (Evans et al., 2011; Kramer et al., 1987; Kok, 2001; Polich, 2007; Strayer & Drews, 2007; Watter et al., 2001; Wickens et al., 1983). A decreased P3b amplitude reflects a greater updating demand. A relation between the amplitude of the P3b component and updating ability has been found in both adults and children (Brydges et al., 2014; Evans et al., 2011). Given that we expect to find a modification of the P3b but not the P3a, we refer to the P3b as P300 in the remainder of this article. Previous studies that investigated phrase and sentence production have also found modulations of the P300 that were related to the demands on the updating of working memory (Marek, Habets, Jansma, Nager, & Münte, 2007; Habets, Jansma, & Münte, 2008). However, in these studies, the P300 amplitude was larger in more difficult than in easier conditions, different from the results using non-linguistic tasks referred to above. We further discuss this issue below.

It is unclear whether shifting is reflected in the P300. Using tasks with binary manual responses, some prior studies have obtained P300 switching effects (Karayanidis, Coltheart, Michie, & Murphy, 2003; Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000; Rushworth, Passingham, & Nobre, 2002), whereas other studies did not find an effect (Hsieh, 2006; Hsieh & Yu, 2003; Hsieh & Liu, 2005; Poulsen, Luu, Davey, & Tucker, 2005). The present study examined whether the amplitude of the P300 is modulated by shifting in spoken phrase production.

Outline of the present study

Following Sikora et al. (2015), we assessed language production performance using a picture description task and a picture-word interference procedure. We measured ERPs to assess how length, distractor, and switch effects are reflected in the N200 and P300 components. More specifically, based on the literature (reviewed in an earlier section), we expected that the distractor and switch effects would be reflected in the anterior and posterior N200 subcomponents, respectively, and the length effect in the P300. Moreover, we expected a length effect in the anterior N200 (i.e., more inhibition during the production of long than short phrases) and an interaction between length and switch in the posterior N200 (harder shifting to short than long phrases due to the differential inhibition). Additionally, we expected that the magnitude of the ERP effects would correlate with the magnitude of the corresponding RT effects. Theoretically, a speaker must shift to the relevant task set (e.g., to produce a long phrase) and inhibit an irrelevant task set (to produce a short phrase) before the required phrase can actually be planned, which requires the updating ability. This would imply that the shifting and inhibiting abilities are engaged before the updating ability, in line with the association of shifting and inhibiting with the N200 and updating with the P300.

Method

Participants

Twenty-eight native speakers of Dutch participated in the experiment (23 women and 5 men, mean age = 23.75 years, age range: 19 to 34 years). The participants were recruited via the Radboud University SONA system. They received 25 Euros or 2.5 credit for their participation.

Design and behavioral procedure

The participants signed the informed consent before the experimental session. After the experimental session, participants were debriefed and paid for their participation. An experimental session lasted about 2 hour and 30 minutes.

Participants had to describe a picture presented in the middle of a computer screen while trying to ignore a spoken distractor that was played via headphones. Each trial began with a fixation cross which remained on the screen for 700 ms, followed by the presentation of a spoken distractor and a picture simultaneously (i.e., with the same presentation onset). The picture remained on the screen for 250 ms followed by a blank screen for 2450 ms. To concentrate on the influences of executive control and to reduce variance due to differences in processing speed among pictures and words, only a limited number of objects and colors were used. The set of stimuli consisted of four pictures, namely a bottle, a plate, a glass, and a fork, and four spoken distractors, which were the names of these objects. All spoken distractors were monosyllabic Dutch words, which were all semantically related (like in the color-word Stroop task, e.g., Roelofs, 2003). Two nouns had non-neuter grammatical gender, taking the definite article *de*, and two nouns had neuter gender, taking the definite article *het*. Different from Sikora et al. (2015), the experiment did not have an indefinite-phrase condition. There were two practice blocks and ten experimental blocks of trials. Participants had to describe all the pictures using noun phrases with a definite article and ignore the spoken distractors. Each experimental block consisted of 32 trials. In total there were 320 trials. We used the program Mix (Van Casteren & Davis, 2006) to randomize our stimulus lists. A restriction on the randomization was that stimuli were not allowed to repeat on consecutive trials.

The picture names and the spoken distractors could be either two identical nouns (congruent condition) or two different nouns taking the same grammatical gender (incongruent condition). These distractor conditions had the same number of trials. The pictures where either black-and-white drawings or colored drawings, either blue or green. The participants were instructed to produce determiner-noun phrases (e.g., "de vork", the fork) when the presented picture was a black-and-white drawing, the short phrase condition. When the picture was presented in one of the two colors, the participants had to produce a phrase that included an article, a color adjective, and the name of the object (e.g., "de groene vork", the green fork), the long phrase condition. The number of trials for these conditions was the same. The pictures were presented such that the required phrase type changed every second trial. Thus, in the trial sequence, two black-and-white pictures were followed by two colored pictures, which were followed by two black-and-white pictures, etc. The number of trials for the repeat and switch conditions was equal.

EEG procedure

The EEG was recorded from 32 cap-mounted active Ag/AgCl electrodes. Additionally, four electrodes were used to monitor horizontal and vertical eye movements and two electrodes were used to monitor mouth movements. Moreover, two electrodes were placed on the right and left mastoid bones. The signal was amplified with BrainAmps DC amplifiers with a 125 Hz low-pass filter, 500 Hz sampling frequency and a time constant of 10 s. Electrode impedance of the recording was kept below 5 kΩ. All electrodes were referenced on-line to the FCz electrode and re-referenced off-line to averaged mastoids.

RT analysis

The data of six participants were excluded from the analysis due to technical errors in the EEG recording. In total, the data of 22 subjects were included in the analysis. Moreover, responses were excluded from the analysis if the produced phrase did not match the correct phrase or when the response included any kind of disfluency or was not completed before the end of a trial. Mean RTs were calculated for long phrase, short phrase, congruent distractor, incongruent distractor, repeat trials, and switch trials. Repeated measures ANOVAs were conducted to test for main effects and interactions between conditions. Three effects were defined: length (short vs. long phrase), distractor (congruent vs. incongruent), and switch (repeat vs. switch trials).

EEG analysis

EEG analyses were performed using the software Brain Vision Analyzer (Brain Products, Germany). Trials excluded from the RT analysis were also discarded from the EEG analysis. The EEG electrodes were re-referenced to the averaged right and left mastoids. Single waveforms were filtered with a 30 Hz, 12 dB low-pass filter. Thereafter, segments starting 200 ms before and 600 ms after stimulus onset were formed. The segments were baseline-corrected using the 200-ms window before stimulus onset, and they were screened for eye movements, electrode drifting, and EMG artifacts with a 75-µVolt criterion. After the artifact rejection, there were at least 30 trials left per participant per condition. Next, averaged ERPs were computed per participant and per condition.

The effects of length, distractor, and switch were evaluated at the midline electrodes (Fz, Cz, Pz) for N200 and P300 modulations. Based on the literature and visual inspection of the waveforms, the time windows for the N200 and P300 were, respectively, from 250 ms to 400 ms (N200) and from 400 ms to 600 ms (P300). A repeated measures ANOVA was conducted for each of the time windows. Moreover, four quadrants were defined: right anterior (F4, F8, FC2, FC6, C4), left anterior (F3, F7, FC1, FC5, C3), right posterior (CP2, CP6, P4, P8, O2), and left posterior (CP1, CP3, P3, P7, O1). The effects of length, distractor, and switch were also evaluated for the four quadrants. In addition, we analyzed correlations among the three main effects in the RTs and in the ERPs at the midline sites (Fz, Cz, Pz).

Results

Behavioral performance

Mean reaction times and error rates for each of the conditions are presented in Table 1. Mean RTs were longer for the incongruent than the congruent condition (distractor effect), longer for the long phrase than for the short phrase condition (length effect), and longer for the switch condition than for the repeat condition (switch effect).

The statistical analysis of the RTs revealed that there was a main effect of distractor, indicating that participants were slower in the incongruent than in the congruent condition, $F(1, 21) = 50.98$, $MSE = 33684$, $p < .001$, $\eta_p^2 = .71$. There was also a main length effect, indicating that participants were slower in the long phrase than in the short phrase condition, $F(1, 21) = 12.06$, $MSE = 46877$, $p < .01$, $\eta_p^2 = .37$. We also found a main switch effect, indicating that participants were slower in the switch than in the repeat condition, $F(1, 21) = 6.42$, $MSE = 1657$, $p < .05$, $\eta_p^2 = .23$.

Additionally, we found an interaction between length and switch, $F(1, 21) = 16.53$, $MSE = 16717$, $p < .001$, $\eta_p^2 = .44$. Figure 1 shows the RT pattern. Post-hoc analysis revealed that the switch effect was present for the short phrases, $t = 5.42$, $p < .001$, but not for the long phrases, $t = -1.66$, $p = .112$. There were no other interactions.

To summarize, the present study obtained length, distractor, and switch effects, and an interaction between length and switch. These behavioral findings replicate Sikora et al. (2015).

Table 1: Mean reaction times (milliseconds) and percentage error (between parentheses) in the picture-description task.

		Switch		
Distractor	Length	Repeat	Switch	*Total*
Congruent	Long	712 (12)	697(14)	705 (13)
	Short	644 (6)	679 (6)	660 (6)
	Total	678 (9)	687 (10)	683 (9)
Incongruent	Long	748 (17)	742 (19)	745 (18)
	Short	689 (9)	710 (9)	698 (9)
	Total	717 (13)	726 (14)	722 (14)
Total	Long	730 (15)	720 (16)	725 (15)
	Short	665 (7)	693 (7)	679 (7)
	Total	698 (11)	707 (12)	702 (11)

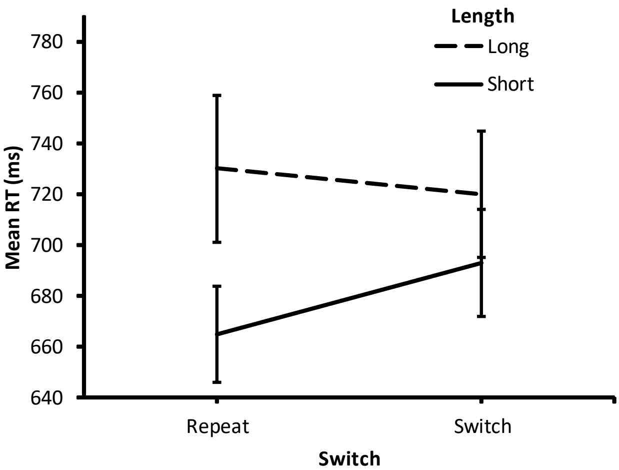

Figure 1: Mean response time (RT) for the picture descriptions per length condition (short, long) on repeat and switch trials. The error bars indicate one standard error.

Electrophysiological findings

Figure 2 presents grand-averaged ERP waveforms at the three midline electrodes (Fz, Cz, Pz) for the switch (repeat vs. switch), distractor (incongruent vs. congruent), and length (short vs. long phrase) conditions. Figure 3 presents topographic maps for the switch, distractor, and length effects for the 0-250 ms, 250-400 ms (N200), and 400-600 ms (P300) time windows. For the 0-250 ms time window, no significant effects were obtained.

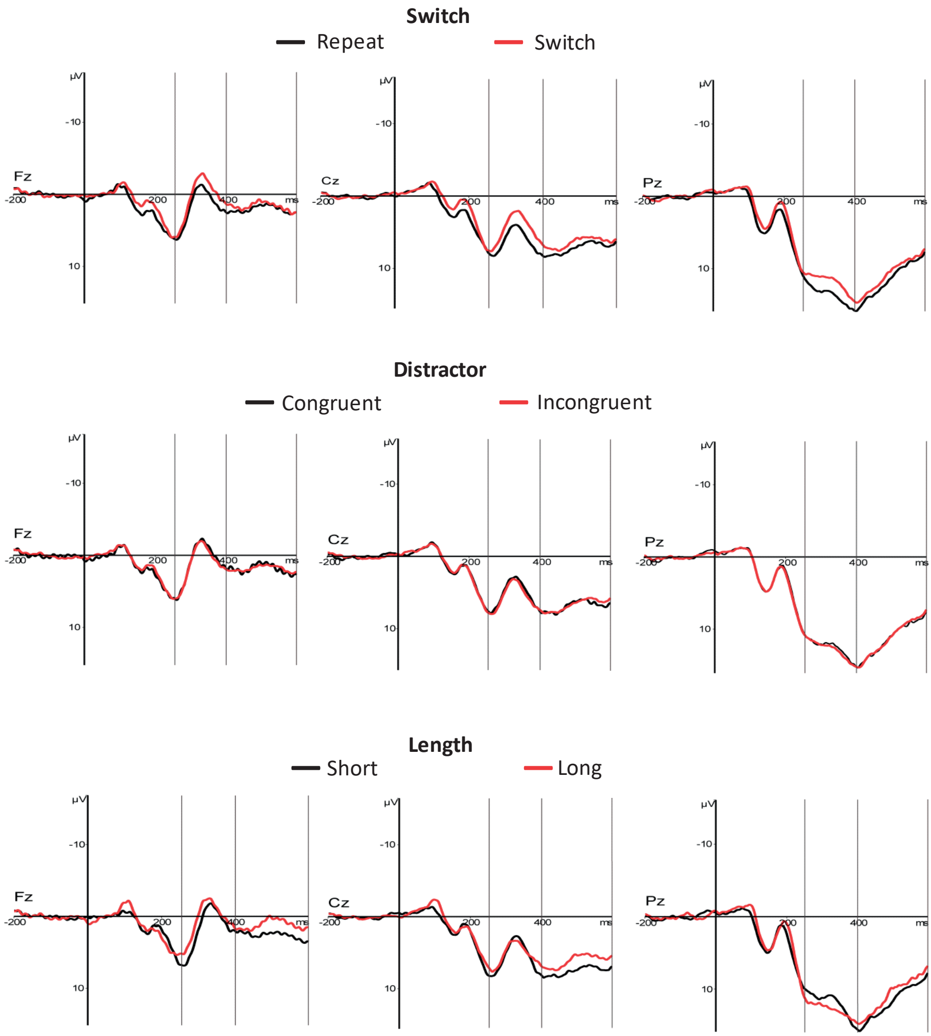

Figure 2: Grand-averaged ERP waveforms at the three midline electrodes (Fz, Cz, Pz) for the switch (repeat vs. switch), distractor (incongruent vs. congruent), and length (short vs. long) conditions. The gray vertical lines indicate the 250-400 ms (N200) and 400-600 ms (P300) time windows.

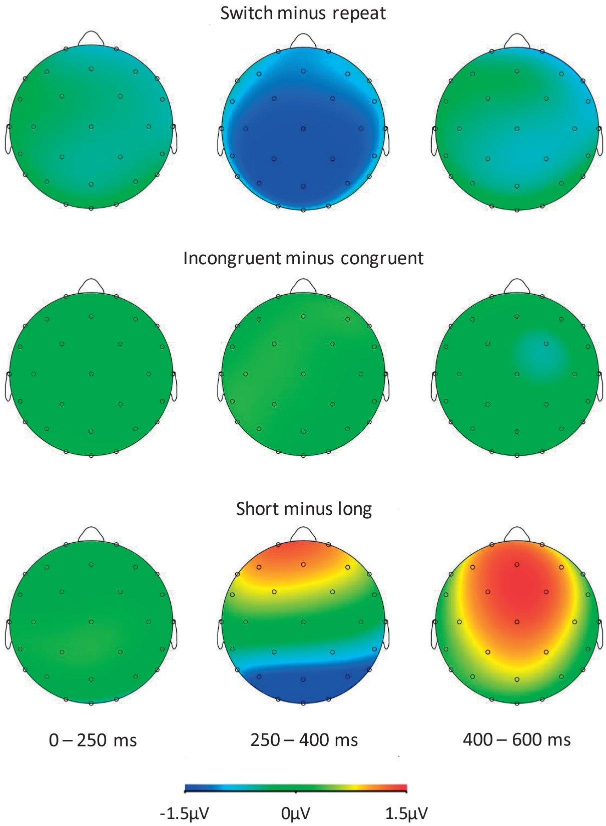

Figure 3: Topographic maps for the switch, distractor, and length effects for the 0-250 ms, 250-400 ms (N200), and 400-600 ms (P300) time windows.

250-400 ms (N200) window. At the midline sites (Fz, Cz, Pz), we found a main switch effect, $F(1, 21) = 15.89$, $MSE = 338.25$, $p < .001$, $\eta_p^2 = .43$. There was a larger negative-going ERP amplitude for the switch trials than for the repeat trials. Moreover, we found no main effect of length, but there was an interaction between electrode and length, $F(1, 21) = 14.45$, $MSE = 95.60$, $p < .001$, $\eta_p^2 = .41$. Post-hoc analysis revealed that there was a significant length effect at the frontal electrode (Fz), $t = -2.34$, $p < .05$, with the N200 amplitude being larger for the long phrases than for the short phrases (anterior N200). There was also a significant length effect at the parietal electrode (Pz), $t = 2.45$, $p < .05$, with the N200 amplitude being smaller for the long phrase condition than for the short phrase condition (posterior N200). At the central electrode (Cz), the length effect was not significant, $t = -1.0$, $p = .34$. Thus, the length effect in the N200 changed direction between frontal and parietal electrodes (i.e., from long > short to long < short).

The quadrant analysis also revealed a main switch effect, $F(1, 21) = 18.29$, $MSE = 251.74$, $p < .001$, $\eta_p^2 = .47$. The ERP amplitude was more negative-going for the switch trials than for the repeat trials. Moreover, we found an interaction between quadrant and length, $F(3, 63) = 12.40$, $MSE = 52.49$, $p < .001$, $\eta_p^2 = .37$. Post-hoc analysis revealed that the length effect in the N200 was present for the posterior right quadrant, $t = 3.00$, $p < .01$, and posterior left quadrant, $t = 2.30$, $p < .05$, but not for the anterior quadrants. For both posterior quadrants, there was more negative-going ERP amplitude for the short phrase condition than for the long phrase condition, in line with the midline analysis. We also found an interaction between quadrant, length, and switch, $F(3, 63) = 3.50$, $MSE = 9.07$, $p < .05$, $\eta_p^2 = .14$. Post-hoc analysis revealed that the interaction between length and switch was present for the posterior right quadrant, $F(1, 21) = 10.15$, $MSE = 27.34$, $p < .01$, $\eta_p^2 = .33$, and for the posterior left quadrant, $F(1, 21) = 4.86$, $MSE = 20.76$, $p < .05$, $\eta_p^2 = .19$, but not for the anterior right quadrant, $F(1, 21) = .001$, $MSE = 0.01$, $p = .97$, $\eta_p^2 = .00$, and for the anterior left quadrant, $F(1, 21) = .05$, $MSE = .42$, $p = .83$, $\eta_p^2 = .002$. For the posterior right quadrant, switch and repeat trials did not differ for the long phrase condition, $t = -.96$, $p = .35$, while in the short phrase condition there was a more negative N200 for the switch than for the repeat trials, $t= -4.88$, $p <.001$. Similar, for the posterior left quadrant, switch and repeat trials did not differ for the long phrase condition, $t = -1.29$, $p = .21$, while in the short phrase condition there was a more negative N200 for the switch than for the repeat trials, $t = -3.72$, $p < .001$.

400-600 ms (P300) window. At the midline sites (Fz, Cz, Pz), we found a significant main effect of length, $F(1, 21) = 8.0$, $MSE = 267$, $p < .01$, $\eta_p^2 = .27$. In particular, there was a smaller positive-going ERP amplitude for the long than for the short phrase condition.

We did not find any significant main effects for the quadrant analysis in the late time window. However, the main length effect was marginally significant, $F(1, 21) = 3.74$, $MSE = 96.15$, $p = .07$, $\eta_p^2 = .15$. The positive ERP amplitude was smaller for the long than for the short phrases.

To summarize, the ERP findings suggest the following time course of effects. In the N200 time window (250-400 ms), a switch effect is obtained that is widely distributed across the scalp. Switch trials yield a larger negativity than repeat trials. Moreover, the switch effect interacts with length at posterior electrode sites (posterior N200). The larger negativity for switch than repeat trials is obtained for the short phrases but not for the long phrases. Length interacts with electrode at midline sites: The N200 was larger for the long than short phrases at the frontal site (anterior N200) and smaller for long than short at the parietal site (posterior N200). In the P300 time window (400-600 ms), only a main effect of length is obtained. A smaller positivity is obtained for the long phrases than for the short phrases. Distractor did not yield an effect in any of the time windows.

Correlations between the electrophysiological and behavioral responses

We analyzed the correlations among the three effects (length, distractor, switch) in the RTs and in the ERPs. We conducted the analysis at the midline electrodes for the time windows of 250-400 ms and 400-600 ms. We tested for correlations between the distractor and switch effects in the RTs and the N200, and between the length effect in the RTs and the P300. In the N200 time window, we found a significant negative correlation between the magnitude of the switch effect in the RTs and the ERPs at the frontal electrode (Fz), $r = -.39$, $p < .05$, but we found no correlation for distractor. In the P300 time window, we found a significant negative correlation between the magnitude of the length effect in the RTs and ERPs at the parietal (Pz) and at the central (Cz) electrodes, $r = -.61$, $p < .01$, and $r = -.41$, $p < .05$, respectively.

Discussion

The current study investigated the electrophysiological basis and dynamics of updating, inhibiting, and shifting in noun-phrase production. We measured how an increase in demand on updating, inhibiting, and shifting modulated noun-phrase production RTs and electrophysiological components, in particular, the N200 and P300. Our RT and ERP results generally confirmed the expectations outlined earlier, except that we found a distractor effect only in RTs but not in ERPs. We obtained switch effects in RTs and the N200, which was widely distributed across the scalp. The amplitude of the N200 was larger for switch than for repeat trials. Moreover, the switch effect interacted with length at posterior electrode sites and in RTs. As expected, the amplitude of the posterior N200 was larger for switch than repeat trials for the short phrases but not for the long phrases, and the RT switch effect was present for the short but not for the long phrases. This is in line with the assumption that in switching between phrase types, it is more difficult to overcome previous inhibition in switching to short phrases (previously inhibited) than to long phrases (not inhibited). We also obtained evidence for the differential inhibition of long and short phrases. In line with the assumption that the task set for short phrases is inhibited during the production of long phrases, the amplitude of the anterior N200 was larger for the long than the short phrases.

In the posterior N200, the reverse effect was obtained, suggesting greater difficulty in overcoming previous inhibition for short than long phrases. Finally, we obtained a length effect in RTs and the P300. The P300 amplitude was smaller on long- than short-phrase trials, in line with the assumption of greater engagement of the updating ability on long- than short-phrase trials.

We argued that, theoretically, speakers must shift to the relevant task set (e.g., to produce a long phrase) and inhibit an irrelevant task set (to produce a short phrase) before the required phrase can actually be planned, which requires the updating ability. Based on this, we expected that the shifting and inhibiting abilities would be engaged before the updating ability, in line with the association of shifting and inhibiting with the N200 and updating with the P300. Our ERP results confirmed these expectations, providing evidence that inhibiting and shifting of task set are engaged before updating in phrase planning. In the remainder of this article, we further discuss these findings in more detail and relate them to existing findings in the literature. In particular, we further discuss the N200 effects and the P300 effect.

N200 effects

We observed that widely distributed across the scalp, the N200 was larger for switch than repeat trials. Moreover, in the midline analysis, the N200 was larger for long than short phrases at the frontal electrode (anterior N200) and larger for short than long phrases at the parietal electrode (posterior N200). Moreover, in the posterior quadrants, the N200 was larger for switch than repeat trials for the short but not for the long phrases. The latter finding is in line with the interaction between length and switching obtained in the RTs.

Previous research has suggested that the anterior N200 is associated with inhibition and the posterior N200 with shifting. Our finding of a broadly distributed switch effect would suggest that switching between phrase types not only engages the shifting ability (which would be reflected at posterior sites) but also the inhibiting ability (which would be reflected at anterior sites). The involvement of inhibition in switching between phrase types agrees with evidence that inhibition is also involved in switching between languages (Jackson et al., 2001; Meuter & Allport, 1999) and in task switching (Allport & Wylie, 1999, 2000; for a review, see Koch, Gade, Schuch, & Philipp, 2010). The asymmetrical switch cost in the RTs that we obtained (i.e., a switch effect for the short but not for the long phrases) corresponds to the asymmetrical switch costs often obtained in language switching and in task switching. For example, switch costs tend to be larger for the stronger language (L1) than the weaker language (L2) and larger for the stronger task (e.g., Stroop reading) than the weaker task (e.g., Stroop color naming). The asymmetrical switch cost is often interpreted in terms of differential task-set inertia. In performing the weaker language or task, the weaker task set should be enhanced or the competing task set for the stronger language or task should be inhibited. As a consequence, in switching to the stronger language or task, the previous inhibition should be overcome or the previous enhancement of the weaker task should be overcome. This prolongs RTs on switch trials for the stronger language or task.

Similarly, in producing long phrases, the task set for producing short phrases (allowed by a colored picture) needs to be inhibited, whereas in producing short phrases, the task set for producing long phrases (not allowed by a black-and-white picture) does not need to be inhibited. This explains the length effect we obtained for the anterior N200 (i.e., a lager N200 for long than short phrases). Presumably, more inhibition is needed on switch than repeat trials, but we obtained no interaction between length and switch in the anterior N200. However, this absence of an interaction may be due to insufficient power given that the effect was assessed for only one electrode (Fz). Similarly, the posterior interaction between length and switch (i.e., a switch effect for short but not for long phrases) was obtained in the quadrant analysis (which included several electrodes) but not in the midline analysis (which concerned only one posterior electrode, Pz). In the posterior quadrants, the N200 was larger for the short than the long phrases, in line with the assumption that in switching to a short phrase, the previous inhibition of its task set needs to be overcome.

We obtained a negative correlation between the switch effect in RTs and the anterior N200. This suggests that stronger engagement of the inhibiting ability reduces the RT switch effect. This is in line with the findings of Shao et al. (2014), who observed a similar negative correlation between name-agreement affects in the anterior N200 and picture naming RTs.

Contrary to our expectations, we did not find a distractor effect in the N200 component, and also no correlations. It is unclear why we failed to find the ERP distractor effect. We can exclude the possibility that the distractor manipulation was unsuccessful because we did find the distractor effect in RTs. Subjects responded slower on incongruent than congruent trials. A possible reason for the lack of an N200 distractor effect might be the modality of the distractors used in our study. Previous studies examining the electrophysiology of Stroop or Stroop-like tasks used visual distractors (e.g., Holmes & Pizzagalli, 2008; Silton et al., 2010). In the current study, we used auditory distractors. In a previous ERP study examining semantic effects of spoken distractors in picture naming, Aristei, Melinger, and Abdel Rahman (2011) also obtained no significant distractor effect. Moreover, it has been observed that the N200 effect for no-go versus go trials in the stop-signal task is much smaller or absent if an auditory version of the task is used (e.g., Falkenstein, Hoormann, & Hohnsbein, 1999). Thus, it seems possible that the use of auditory distractors in our study could be the reason why we did not find an N200 effect. However, further studies need to be carried out in order to investigate whether auditory distractors in Stroop-like tasks yield attenuated or no N200 modulations.

Taken together, our findings suggest that the greater executive-control demand on switch than repeat trials slows down phrase production and increases the N200 broadly across the scalp. Moreover, the larger anterior N200 for the long than for the short phrases suggests stronger involvement of inhibition on the long- than the short-phrase trials. As a consequence, a switch asymmetry is obtained in the posterior N200: For the short but not the long phrases previous inhibition need to be overcome. These findings point to a complex relation between inhibiting and shifting abilities in switching between phrase types in language production.

P300 effect

We found that the long phrases yielded longer RTs and a smaller P300 amplitude than the short phrases. In the short phrase condition, subjects had to process and maintain in working memory two parts of the phrase, the determiner and the noun, while in the long phrase condition they had to process and maintain three parts, namely the determiner, the adjective, and the noun. Thus, the long phrases required more updating of working memory than the short phrases, which was reflected in the longer RTs and the smaller amplitude of the P300. This finding is in line with previous research using non-linguistic tasks, which observed a smaller P300 amplitude in conditions with higher demand on updating (Evans et al., 2011; Watter et al., 2001). Moreover, the negative correlation between the length effects in the RTs and P300 suggests that greater engagement of the updating ability (i.e., a larger P300 effect) leads to a reduction of the length effect in the RTs.

However, previous studies that investigated phrase and sentence production have found increases of the P300 that were related to greater demand on the updating of working memory (Marek et al., 2007; Habets et al., 2008). In the study of Marek et al., participants produced phrases in easy, medium, and difficult conditions. In the easy condition, a phrase had to be produced to describe the direction of an arrow (e.g., "downwards"), in the medium condition, the phrase had to describe the direction and destination shape (e.g., "downwards to the triangle"), and in the difficult condition, the phrase had to describe the direction, destination shape, and its color (e.g., "downwards to the grey triangle"). Marek et al. found that the amplitude of the P300 was larger in the medium and difficult conditions than in the easy condition. In the study of Habets et al. (2008), participants had to produce sentences using temporal connectives (i.e., *before* or *after*) and verbs. The sentences had to be produced in response to sequentially presented objects (e.g., first a book was presented, and then a couch) in chronological order ("After I read (book), I sit (couch)") or non-chronological order (e.g., "Before I sit (couch), I read (book)"). Habets et al. observed that the amplitude of the P300 was larger in non-chronological than in the chronological condition, which was attributed to a greater demand on the updating of working memory in the more difficult, non-chronological condition. Thus, similar to our results, these studies show that differences in updating demand modulate the P300. However, whereas we have found a larger P300 in the easier condition (i.e., in producing the short phases), the studies by Marek et al. and Habets et al. found a smaller P300 in the easier condition. As indicated, our results are in agreement with previous non-linguistic studies showing that more demanding conditions elicit a smaller P300 amplitude than less demanding conditions (Evans et al., 2011; Kramer et al., 1987; Kok, 2001; Polich, 2007; Strayer & Drews, 2007; Watter et al., 2001; Wickens et al., 1983).

It is unclear why a larger P300 amplitude reflects greater updating demand in some studies but a smaller demand in others. Kok (2001) suggested that the amplitude of the P300 may reflect the amount of capacity allocated to meet the task demands (i.e., a larger P300 means that more capacity is allocated) or the amount of capacity that is consumed (i.e., a larger P300 means that less capacity is consumed). If participants allocate more capacity in difficult than easier conditions to meet the task demands, and this difference is preserved despite differential consumption, then the P300 amplitude will be larger in difficult than easier conditions, in line with the results of Marek et al. (2007) and Habets et al. (2008). In contrast, if participants do not allocate more capacity in difficult than easier conditions, or if they do but this difference is counteracted by differential consumption, then the P300 amplitude will be smaller in difficult than easier conditions, in line with our results and those of several non-linguistic studies in the literature. Future research may further examine these possibilities. Important for now is that we observed that differences in updating demand modulate the P300, in line with what Marek et al. and Habets et al. found for phrase and sentence production, and what other studies found for non-linguistic tasks.

We found no switch effect in the amplitude of the P300. The evidence in the literature for task switching effects on the P300 is mixed. Whereas some studies have reported P300 switching effects (Karayanidis et al., 2003; Lorist et al., 2000; Rushworth et al., 2002), other studies found no effect (Hsieh, 2006; Hsieh & Yu, 2003; Hsieh & Liu, 2005; Poulsen et al., 2005). However, all these studies used manual left/right responding in rather simple tasks, such as switching between color categorization (red, blue) and letter categorization (vowel, consonant). Thus, even if we take these earlier studies to suggest that switching modulates the amplitude of the P300, it would remain an open question whether previous results obtained with binary manual tasks (i.e., pressing left or right buttons) generalize to other more complex tasks such as spoken noun-phrase production. In the present study, switching between phrase types did not modulate the P300 amplitude, suggesting that previous results from manual tasks do not straightforwardly generalize to spoken phrase production.

To summarize, we found evidence that producing long phrases prolongs RTs and reduces the P300 compared to producing short phrases. The larger the P300 effect, the smaller the RT effect. This suggests that a greater engagement of the updating ability leads to a smaller RT difference between long and short phrases.

Conclusion

The present study provided evidence on the electrophysiological basis and dynamics of the involvement of updating, inhibiting, and shifting abilities in noun-phrase production. In picture description RTs, length, distractor, and switch effects were obtained, which have been associated with the updating, inhibiting, and shifting abilities. A switch effect was obtained in the N200, widely distributed across the scalp, and length effects were found in the anterior and posterior N200, and in the P300. Moreover, length and switch interacted in the posterior N200. We argued that these findings suggest that inhibiting and shifting of task set occur before updating in phrase planning.


LANGUAGE
PRODUCTION
UPDATING
INHIBITING
SHIFTING

CHAPTER 4

Switching between language-production tasks: The role of attentional inhibition and enhancement

A version of this chapter appeared as: Sikora, K., & Roelofs, A. (2018). Switching between language-production tasks: The role of attentional inhibition and enhancement. *Language, Cognition and Neuroscience.* Advance online publication. DOI: 10.1080/23273798.2018.1433864

Abstract

Since Pillsbury (1908), the issue of whether attention operates through inhibition or enhancement has been on the scientific agenda. Here, we examined whether overcoming previous attentional inhibition or enhancement is the source of asymmetrical switch costs in noun-phrase production and color-word Stroop tasks. In Experiment 1, using bivalent stimuli, we found asymmetrical costs for switching between long and short phrases and between Stroop color naming and reading. However, in Experiment 2, using bivalent stimuli for the weaker tasks (long phrases, color naming) and univalent stimuli for the stronger tasks (short phrases, word reading), we obtained an asymmetrical switch cost for phrase production, but a symmetrical cost for Stroop. These findings suggest that switching between phrase types involves inhibition, whereas switching between color naming and reading involves enhancement. Thus, the attentional mechanism depends on the language-production task involved.

Introduction

In daily life, people must often switch between tasks, such as between writing an email and answering the phone, each of which is governed by a task set that specifies the required processes. In the past few decades, research on task switching has been dominated by studies of switching between simple tasks requiring discrete manual or vocal responses (e.g., Monsell, 2015, for a review). For example, participants had to switch between parity (odd/even) and magnitude (larger/smaller than five) judgments in response to digits, or between color naming and word reading in response to color-word Stroop stimuli. Switch costs concern the difference in response time (RT) between trials that repeat the task of the previous trial (repeat condition) and trials in which the task is different from the previous trial (switch condition). Asymmetrical switch costs (i.e., a larger cost for one task than the other) have been repeatedly observed in switching between tasks of different strengths, like color naming and word reading (e.g., Koch, Gade, Schuch, & Philipp, 2010, for a review). Hereby, larger costs are obtained for switching to the stronger tasks, such as word reading in case of Stroop task-switching (e.g., Allport & Wylie, 1999, 2000). However, asymmetrical switch costs are not always obtained for tasks of different strength, but symmetrical costs may be obtained as well under certain circumstances (e.g., Yeung & Monsell, 2003).

Recently, asymmetrical switch costs were obtained for switching between more complex nondiscrete tasks, in particular, for switching between types of noun phrases in spoken picture description (Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016). Switching in phrase production yielded a larger cost for switching to short phrases (stronger task) than to long phrases (weaker task). The asymmetrical switch cost may be explained in terms of task-set inertia involving attentional inhibition of the stronger task set, as has been proposed in the task-switching Stroop literature (e.g., Allport & Wylie, 1999, 2000). However, as we explain below, it has remained unclear whether Stroop switching actually involves attentional inhibition or enhancement of task sets. Since Pillsbury (1908), it is acknowledged that attention may operate through inhibition or enhancement depending on the task and experimental circumstances. The aim of the research reported in the present article was to examine the source of asymmetrical switch costs (i.e., inhibition or enhancement) by directly comparing switching in noun-phrase production and in color-word Stroop tasks.

In the remainder, we first briefly review previous findings on asymmetrical switch costs and we discuss the task-set inertia account, which explains the asymmetrical cost in terms of differential inhibition or enhancement of task sets. Next, we describe the task-switching paradigm that we used in two experiments to examine switch costs in noun-phrase production and in color-word Stroop tasks, and we report our experimental results. Finally, we discuss the consequences of our findings for the issue of inhibition or enhancement of task sets in noun-phrase production and color-word Stroop.

Asymmetrical switch costs and task-set inertia

In task switching, asymmetrical switch costs have often been obtained. For example, in a study investigating switching between languages, Meuter and Allport (1999) observed a larger switch cost for switching to the stronger first language than to the weaker second language of bilingually-unbalanced speakers. A similar switch cost asymmetry has often been reported for the color-word Stroop task when participants switch between color naming and word reading. In the Stroop task, participants name the ink color of incongruent color words (e.g., the word *red* in green ink) or neutral series of Xs, or alternatively, they read aloud the incongruent colors words or words in neutral black ink (e.g., MacLeod, 1991). The switch cost in RTs is larger for switching to the stronger reading task than to the weaker color naming task (e.g., Allport & Wylie, 1999, 2000). To explain this paradoxical switch cost asymmetry, Allport and colleagues proposed a task-set inertia account. According to this account, when performing a weaker task (e.g., color naming or naming in a second language), its task set must be enhanced or the task set of the irrelevant stronger task (e.g., word reading or naming in the first language) must be inhibited. Consequently, in switching from the weaker task to the stronger task, the previous enhancement of the weaker task or the previous inhibition of the stronger task must be overcome, which will increase RTs. In contrast, in switching from the stronger task to the weaker task, there is no such previous enhancement of the target task on the previous trial (which was the stronger task) or previous inhibition of the irrelevant task (which was the weaker task), and RTs will not be increased. As a result, a difference in switch cost between tasks will be obtained.

To test their task-set inertia account, Allport and Wylie (1999, 2000) assessed the costs of switching between word reading and color naming under different Stroop conditions. In one of their studies, they used an alternating runs paradigm, in which participants had to switch every second trial between word reading and color naming. In an all-neutral condition, they used neutral stimuli in both tasks (i.e., colored Xs for color naming and words in black for word reading). In a color-neutral/word-incongruent condition, they used neutral stimuli for color naming (i.e., colored Xs) and incongruent stimuli for word reading (i.e., color words in an incongruent ink color). And in an all-incongruent condition, they used incongruent Stroop stimuli for both word reading and color naming. Allport and Wylie obtained a much larger switch cost for word reading in the all-incongruent than in the color-neutral/word-incongruent condition. The switch cost in the latter condition did not differ from that in the all-neutral condition and was equivalent to the switch cost for color naming in all conditions. These results demonstrate that the switch cost was determined by the task set of the previous trial, which differs between the all-incongruent and color-neutral/word-incongruent conditions for word reading (i.e., incongruent stimuli vs. neutral stimuli for color naming) but not between the color-neutral/word-incongruent and all-neutral conditions (in both conditions, the stimuli for color naming were neutral). Moreover, the switch cost was clearly not determined by the task set of the current trial, which was the same for word reading in the all-incongruent and color-neutral/word-incongruent conditions (in both conditions, there were incongruent stimuli for word reading) but different between the color-neutral/word-incongruent and all-neutral conditions (incongruent vs. neutral stimuli for word reading).

Attentional inhibition versus enhancement of task set

The results of Allport and Wylie (1999, 2000) support the task-set inertia account. However, the results are silent about inhibition and enhancement. In the all-neutral and color-neutral/word-incongruent conditions, symmetrical switch costs were obtained for word reading and color naming, whereas the switch cost was much larger for word reading than for color naming in the all-incongruent condition. In naming the color of incongruent color-word combinations (required only in the all-incongruent condition), the task set for color naming may be enhanced, the task set for reading may be inhibited, or both. To explain the asymmetrical switch cost, it suffices to assume either enhancement of the weaker task set or inhibition of the stronger task set. For example, to explain the asymmetrical switch costs between color naming and reading, it suffices to assume that the task set for color naming is enhanced on color naming trials, whereas there is no such enhancement of the task set for reading on reading trials. Alternatively, it may be assumed that the task set for reading is inhibited on color naming trials, whereas there is no such inhibition of the task set for color naming on reading trials. The existing results do not allow for a distinction between inhibition and enhancement of task set in Stroop task-switching.

Asymmetrical switch costs have not only been obtained for switching between simple discrete tasks, like color naming and word reading, but also for switching between more complex tasks, like switching between types of noun phrases (i.e., Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016). In these studies, participants had to describe black-and-white or colored pictures of simple objects, which were presented in an alternating runs paradigm (i.e., two black-and-white pictures followed by two colored pictures, etc.). In response to the black-and-white pictures, participants produced short noun phrases (e.g., "the fork") and in response to the colored pictures, they produced long noun phrases including a color adjective (e.g., "the green fork"). As expected, smaller RTs were obtained for the short noun phrases than for the long noun phrases. Thus, producing the short phrases can be regarded as the stronger task. Moreover, a switch cost asymmetry was observed: A switch cost was present for the short phrases but not for the long phrases.

The switch cost asymmetry may be explained in terms of task-set inertia. In responding to colored pictures, the task set for producing a long noun-phrase needs to be enhanced or the task set for producing a short noun-phrase needs to be inhibited (e.g., a green fork requires the response "the green fork" but also allows the response "the fork"). In contrast, in responding to black-and-white pictures, there is no need to enhance the task set for producing a short noun-phrase or to inhibit the task set for producing a long noun-phrase (e.g., a black-and-white fork does not allow the response "the green fork"). In switching to a black-and-white picture, the task set for producing a long phrase does not compete (much) with the task set for producing a short phrase, because a black-and-white picture does not allow a phrase with a color adjective (cf. the neural stimuli used by Allport & Wylie, 1999, 2000). Thus, the asymmetrical switch cost must arise because previous inhibition of the task set for producing short phrases must be overcome in switching to trials with black-and-white pictures. This suggests that inhibition of the task set determines the switch cost.

It is important to note that Allport and Wylie (1999, 2000) obtained the asymmetrical switch costs in an all-incongruent condition, which leaves open whether the switch cost is due to inhibition or enhancement of task set. In contrast, Sikora, Roelofs, Hermans, and Knoors (2016) and Sikora, Roelofs, and Hermans (2016) used neutral (black-and-white) stimuli for the stronger short-phrase task and incongruent (colored) stimuli for the weaker long-phrase task. The black-and-white pictures are univalent stimuli, because they afford only one task (i.e., producing the short phrases). The colored pictures are bivalent stimuli, because they afford both tasks (i.e., producing the short as well as the long phrases). The much larger switch cost for the short than the long phrases indicates that the task set for the short phrases was inhibited on trials requiring a long-phrase response. This conclusion can be drawn because enhancement of the task set for producing a long phrase on the trials with colored pictures should not hamper the subsequent production of a short phrase in response to a black-and-white picture (which does not afford long-phrase responses).

Outline of the present study

We conducted two experiments to further examine whether the cost of switching between phrase types reflects inhibition, and to examine whether switching between Stroop color naming and reading involves inhibition or enhancement. In both experiments, participants performed both the phrase production task and the color-word Stroop task. In Experiment 1, we used bivalent stimuli for both phrase production and Stroop. Trials were blocked by type of language task (i.e., phrase production or Stroop). On successive trials, the stimuli (i.e., picture or color-word stimuli) were presented in clockwise rotation in different quadrants of a computer screen. Participants had to perform one task (e.g., short phrases, word reading) when the stimuli appeared in the upper part of the screen and the other task (e.g., long phrases, color naming) when the stimuli appeared in the lower part. We expected to obtain asymmetrical switch costs for both the phrase production task and the color-word Stroop task. This would replicate the Stroop task findings of Allport and Wylie (1999, 2000), who obtained an asymmetrical switch costs in their all-incongruent condition. Moreover, this would show that the findings of Sikora, Roelofs, Hermans, and Knoors (2016) and Sikora, Roelofs, and Hermans (2016) are also obtained when participants produce the short and long phrases always in response to colored pictures. In Experiment 2, we used bivalent stimuli for the weaker tasks (long phrases, color naming) and univalent stimuli for the stronger tasks (short phrases, word reading). For the phrase production task, we should again replicate Sikora et al., because they also used bivalent stimuli for the long phrases and univalent for the short phrases. However, for the Stroop task, symmetrical or asymmetrical switch costs should be obtained depending on whether inhibition or enhancement is present. Asymmetrical costs should be obtained if word reading is inhibited on color naming trials. However, if color naming is enhanced rather than word reading inhibited on color naming trials, then a symmetrical cost should be obtained for Stroop.

Experiment 1

Method

Participants

We tested 16 native speakers of Dutch (14 women and 2 men, mean age = 23.3 years). They were recruited via the Radboud University SONA system. They received 7.50 Euro or 1 credit point for their participation.

Materials, procedure, and design

For phrase production, we used four pictures of simple objects, which were a bottle, plate, glass, and fork. The picture names were all semantically related. The pictures were line-drawings in green, blue, or red color. For the Stroop task, we used (Dutch translations of) the color words *green*, *blue*, and *red* in upper case outline font. The color of the outline filling was always incongruent with the color word (e.g., the word *red* in green color). The average size of the pictures was 738 by 1322 pixels, and the font size of the words was 30 points.

Stimuli were presented in clockwise rotation, beginning in the upper left quadrant of the screen, followed by the upper right quadrant, followed by the lower right quadrant, and the lower left quadrant. Half of the participants were instructed to perform one task (e.g., short phrases, word reading) when the stimuli were presented in the upper part of the screen and to perform the other task (i.e., long phrases, color naming) when the stimuli were presented in the lower part of the screen. The task assignment was reversed for the other half of the participants. Half the participants started with the noun phrase production task and the other half started with the Stroop task. Each stimulus remained on the screen for 250 ms followed by a blank screen for 2000 ms. The stimulus list was randomized using the program Mix (Van Casteren & Davis, 2006) with the restriction that stimuli were not repeated on consecutive trials. For the noun-phrase and Stroop tasks, there was one practice block and five experimental blocks of 48 trials, with a total of 240 trials for each task.

Analysis

Only trials with fluent, correct responses were included in the analysis of the RTs. For phrase production, mean RTs were calculated for short repeat, short switch, long repeat, and long switch trials. For Stroop, mean RTs were calculated for word repeat, word switch, color repeat, and color switch trials. Repeated measures

ANOVAs were conducted to test for main effects and interactions. The factors were task (short vs. long, or word vs. color) and trial type (repeat vs. switch).

Results and discussion

Figure 1 shows the RT results. For phrase production, the mean RT was smaller on repeat trials than on switch trials, $F(1, 15) = 36.67$, $MSE = 826$, $p < .01$, $\eta_p^2 = .71$. The RTs did not differ between short and long phrases, $F(1, 15) = 0.74$, $MSE = 2667$, $p = .40$, $\eta_p^2 = .05$. However, task and trial type interacted, $F(1, 15) = 26.46$, $MSE = 591$, $p < .001$, $\eta_p^2 = .64$. A switch effect was obtained for the short phrases, $t = 8.0$, $p < .001$, but not for the long phrases, $t = 1.30$, $p = .22$. The error percentages for the short repeat, short switch, long repeat, and long switch conditions were 5%, 7%, 13%, and 12.5%, respectively. The statistical analysis revealed a difference between the short (6%) and long phrases (13%), $F(1, 15) = 38.64$, $MSE = .002$, $p < .001$, $\eta_p^2 = .72$, but there was no difference between switch (10%) and repeat (9%) trials, $F(1, 15) = 1.04$, $MSE = .002$, $p = .32$, $\eta_p^2 = .07$. There was no interaction between task and trial type, $F(1, 15) = 3.37$, $MSE = .004$, $p = .09$, $\eta_p^2 = .18$.

Chapter 4

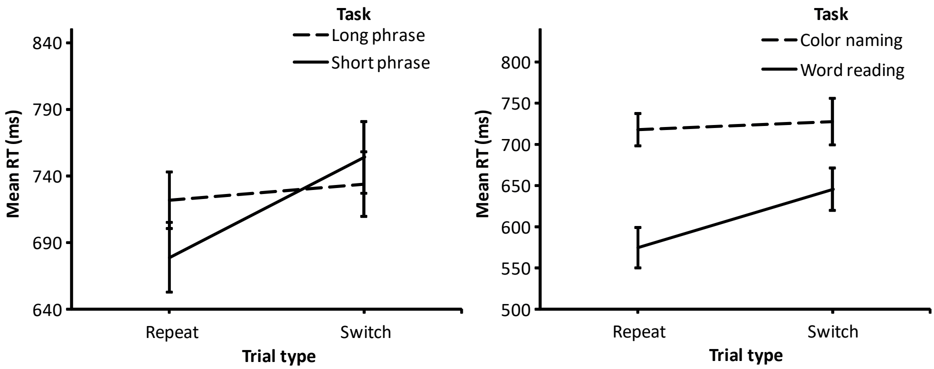

Figure 1: Mean response time (RT) for producing short and long noun-phrases (left panel) and Stroop color naming and reading (right panel) on repeat and switch trials in Experiment 1. The error bars indicate one standard error.

In the Stroop task, mean RT was smaller on repeat trials than on switch trials, $F(1, 15) = 16.11$, $MSE = 1226$, $p < .001$, $\eta_p^2 = .52$. Also, RTs were smaller for word reading than for color naming, $F(1, 15) = 69.38$, $MSE = 2931$, $p < .001$, $\eta_p^2 = .82$. Moreover, task and trial type interacted, $F(1, 15) = 8.65$, $MSE = 7001$, $p < .01$, $\eta_p^2 = .37$. A switch effect was obtained for word reading, $t = -5.20$, $p < .001$, but not for color naming, $t = -0.63$, $p = .54$. The error percentages for the word repeat, word switch, color repeat, and color switch conditions were 2%, 3%, 4%, and 4%, respectively. The statistical analysis yielded no difference between word reading (2.5%) and color naming (4%), $F(1, 15) = 2.20$, $MSE = .001$, $p = .16$, $\eta_p^2 = .13$, and between switch (3.5%) and repeat (3%) trials, $F(1, 15) = 0.86$, $MSE = .001$, $p = .37$, $\eta_p^2 = .05$. There was no interaction between task and trial type, $F(1, 15) = 2.03$, $MSE = .001$, $p = .18$, $\eta_p^2 = .12$.

The asymmetrical switch cost for phrase production replicates the findings of Sikora, Roelofs, Hermans, and Knoors (2016) and Sikora, Roelofs, and Hermans (2016). The present findings show that the asymmetry is also obtained when participants produce the short and long phrases always in response to colored pictures. The asymmetrical switch cost for the Stroop task replicates the findings of Allport and Wylie (1999, 2000).

Experiment 2

The second experiment was the same as Experiment 1, except that we used bivalent stimuli for the weaker tasks (long phrases, color naming) and univalent stimuli for the stronger tasks (short phrases, word reading). For the phrase production task, we should replicate the asymmetrical switch cost obtained in Experiment 1. However, for the Stroop task, symmetrical or asymmetrical switch costs should be obtained depending on whether inhibition or enhancement is present.

Method

Participants

We tested 16 new participants, who were native speakers of Dutch (10 women and 6 men, mean age = 22.75 years). As in Experiment 1, they were recruited via the Radboud University SONA system, and they received 7.50 Euro or 1 credit point for their participation.

Procedure, materials, design, and analysis

This was the same as in Experiment 1, except that we now used univalent stimuli (black-and white drawings) for the short phrases and bivalent stimuli (colored drawings) for the long phrases. Similarly, we used univalent stimuli for word reading (color words in outline font with white filling, the same as the color of the background screen) and bivalent stimuli for color naming (color words with incongruent colored filling).

Results and discussion

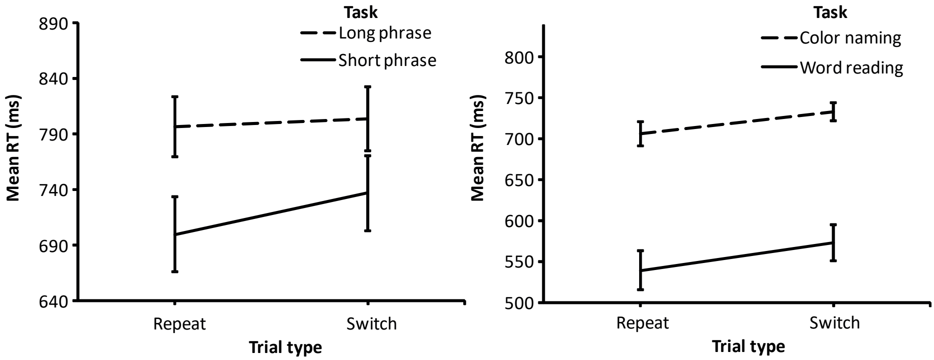

Figure 2: Mean response time (RT) for producing short and long noun-phrases (left panel) and Stroop color naming and reading (right panel) on repeat and switch trials in Experiment 2. The error bars indicate one standard error.

Figure 2 shows the RT results. For phrase production, the mean RT was smaller for the short phrases than for the long phrases, $F(1, 15) = 17.59$, $MSE = 6118$, $p < .001$, $\eta_p^2 = .54$. Also, RTs were smaller on repeat trials than on switch trials, $F(1, 15) = 11.40$, $MSE = 648$, $p < .01$, $\eta_p^2 = .43$. Moreover, there was an interaction between task and trial type, $F(1, 15) = 8.71$, $MSE = 422$, $p < .01$, $\eta_p^2 = .37$. A switch cost was obtained for the short phrases, $t = -4.45$, $p < .001$, but not for the long phrases, $t = -0.78$, $p = .45$. The error percentages for the short repeat, short switch, long repeat, and long switch conditions were 6%, 5%, 11%, and 11%, respectively. The statistical analysis revealed a difference between short (5%) and long phrases (11%), $F(1, 15) = 110.52$, $MSE = .001$, $p < .001$, $\eta_p^2 = .88$. The error percentages did not differ between switch (8%) and repeat (8.5%) trials, $F(1,15) = 0.85$, $MSE = .001$, $p = .37$, $\eta_p^2 = .05$. There was no interaction between task and trial type, $F(1, 15) = 0.30$, $MSE = .005$, $p = .59$, $\eta_p^2 = .02$.

In the Stroop task, mean RT was smaller on repeat than on switch trials, $F(1, 15) = 36.03$, $MSE = 420$, $p < .001$, $\eta_p^2 = .71$. Also, RTs were smaller for word reading than color naming, $F(1, 15) = 81.78$, $MSE = 5243$, $p < .001$, $\eta_p^2 = .85$. However, we did not obtain an interaction between task and trial type, $F(1, 15) = 0.73$, $MSE = 1297$, $p = .41$, $\eta_p^2 = .05$. Thus, there was now no switch cost asymmetry. The error percentages for the word repeat, word switch, color repeat, and color switch conditions were 1.5%, 1%, 4.5%, and 6%, respectively. The statistical analysis revealed a difference between word reading (1%) and color naming (5%), $F(1, 15) = 9.67$, $MSE = .003$, $p < .01$, $\eta_p^2 = .39$. The error percentages did not differ between switch (3%) and repeat (3.5%) trials, $F(1, 15) = 0.71$, $MSE = .001$, $p = .41$, $\eta_p^2 = .05$. There was no interaction between task and trial type, $F(1, 15) = 2.38$, $MSE = .003$, $p = .14$, $\eta_p^2 = .14$.

Combined analysis of Experiments 1 and 2

In the RTs, there was no switch cost for the long phrases in Experiments 1 and 2, whereas the short phrases showed a switch cost in both experiments. Numerically, this switch cost was larger in Experiment 1 than in Experiment 2. We examined whether the switch costs for the short phrases differed statistically between experiments by running a joint analysis of the experiments. We tested for a triple interaction of experiment (first, second), task (short, long), and trial type (repeat, switch). The statistical analysis showed that the overall switch cost was larger in Experiment 1 than in Experiment 2, $F(1, 30) = 5.26$, $MSE = 737$, $p < .001$, $\eta_p^2 = .15$. Moreover, there was a triple interaction of experiment, task, and trial type, $F(1, 30) = 4.10$, $MSE = 506$, $p < .05$, $\eta_p^2 = .12$. The switch effect on the short phrase trials was larger in Experiment 1 than in Experiment 2, $t = 3.05$, $p < .05$.

For the Stroop task RTs, a switch cost asymmetry was obtained in Experiment 1, but the switch costs were symmetrical in Experiment 2. To corroborate that the switch cost patterns differed between experiments, we ran a joint analysis of the experiments. In particular, we tested for a triple interaction of experiment (first, second), task (word reading, color naming), and trial type (repeat, switch). The statistical analysis showed that the overall switch costs did not differ between Experiments 1 and 2, $F(1, 30) = 0.73$, $MSE = 1023$, $p = .40$, $\eta_p^2 = .02$. However, there was a triple interaction of experiment, task, and trial type, $F(1, 30) = 5.59$, $MSE = 1037$, $p < .05$, $\eta_p^2 = .16$. Further analysis revealed that the switch cost on the word reading trials was larger in Experiment 1 than in Experiment 2, $t = -2.42$, $p < .05$, but switch costs did not differ between experiments for color naming, $t = 1.02$, $p = .32$.

Allport and Wylie (1999, 2000) did not use bivalent stimuli for color naming and univalent stimuli for word reading, as we did in our Experiment 2. Our results with these stimuli show that the switch costs are symmetrical, whereas in Experiment 1 the switch costs were asymmetrical.

General discussion

We investigated the source of the asymmetrical switch costs (i.e., previous attentional inhibition or enhancement) in noun-phrase production and color-word Stroop tasks. In Experiment 1, using bivalent stimuli, we obtained asymmetrical switch costs in the RTs for both phrase production and the Stroop task. In Experiment 2, using bivalent and univalent stimuli, we obtained an asymmetrical switch cost for phrase production but a symmetrical switch cost for the Stroop task. These results suggest different sources of the switch costs in noun-phrase production and Stroop.

In the Stroop task in Experiment 1, we used bivalent stimuli for both word reading and color naming. We obtained an asymmetrical switch cost, thereby replicating Allport and Wylie (1999, 2000). The switch cost was larger for word reading than for color naming. According to the task-set inertia account, the large switch cost for word reading was obtained because of the enhancement of the color naming task set on the previous color naming trial or the inhibition of the word reading on the previous color naming trial. However, based on the results of Experiment 1, one cannot tell whether the asymmetrical switch cost was due to inhibition, enhancement, or both. In Experiment 2, we used univalent stimuli for word reading and bivalent stimuli for color naming. Now, a symmetrical switch cost was obtained, which suggests that the switch cost asymmetry in Experiment 1 was due to enhancement. If word reading is inhibited on color naming trials, then an asymmetrical switch costs should be obtained regardless of whether stimuli are incongruent (Experiment 1) or neutral (Experiment 2), unlike what we observed empirically. In contrast, if color naming is enhanced on color naming trials, then an asymmetrical switch cost should be obtained when the stimuli are incongruent (Experiment 1) and a symmetrical switch cost should be obtained when the stimuli are neutral (Experiment 2), which corresponds to what we observed empirically.

For the phrase production task, we obtained asymmetrical switch costs, both when we used bivalent stimuli (Experiment 1) and when we used univalent stimuli for the short phrases and bivalent stimuli for the long phrases (Experiment 2). This suggests that the switch cost asymmetry was due to inhibition. If the task set for short phrases is inhibited on long-phrase trials, then an asymmetrical switch cost should be obtained regardless of whether the stimuli for the short phrases are bivalent (Experiment 1) or univalent (Experiment 2), which corresponds to what we observed empirically. However, as the combined analysis showed, the cost of switching to the short phrases was much larger in Experiment 1 than in Experiment 2 (i.e., 75 ms vs. 37 ms, respectively). This may suggest that the larger switch cost for the short phrases than the long phrases in not only due to inhibition of the task set for short phrases on long-phrase trials, but also to enhancement of the task set for long phrases on long-phrase trials. In switching to black-and-white pictures requiring a short phrase response (Experiment 2), only inhibition can play a role because a black-and-white picture does not afford a long phrase response. However, in switching to a colored picture requiring a short phrase response (Experiment 1), not only inhibition but also enhancement can play a role, because a colored picture affords a long phrase response. As a consequence, not only previous inhibition of the task set for short phrases but also previous enhancement of the task set for long phrases must be overcome, which may increase the switch cost. This would explain why the cost of switching to the short phrases was much larger in Experiment 1 than in Experiment 2. Alternatively, more inhibition may have been applied in Experiment 1 than Experiment 2. This difference may have occurred because short phrases were always produced in response to colored pictures in Experiment 1 but never in Experiment 2, and therefore stronger inhibition of the task set for short phrases may have been required on long-phrase trials in Experiment 1.

To conclude, we obtained evidence that switching to short phrases involves overcoming previous attentional inhibition of the task set for short phrases, and perhaps also overcoming previous enhancement of the task set for long phrases. In contrast, our findings suggest that switching to Stroop reading involves overcoming of enhancement of the task set for color naming only. Thus, the attentional mechanism depends on the language task involved.


LANGUAGE
PRODUCTION
UPDATING
INHIBITING
SHIFTING

CHAPTER 5

Executive control in language production by typical and language-impaired children

A version of this chapter is submitted as: Sikora, K., Roelofs, A., Hermans, D., & Knoors, H. (manuscript submitted). Executive control in language production by children with and without language impairment.

Abstract

Accumulating evidence suggests that executive control is important for spoken language production in adults. Moreover, impaired executive control is reflected in the language comprehension performance of children with specific language impairment (SLI). However, little is known about how executive control is manifest in the language production performance of typical and language-impaired children. In this study, we tested children with SLI and typically developing (TD) children (age 8-12 years) on noun-phrase production using picture description and a picture-word interference paradigm. We measured their production accuracy and speed to assess length, distractor, and switch effects, which reflect the updating, inhibiting, and shifting abilities underlying executive control (Sikora, Roelofs, Hermans, & Knoors, 2016). Moreover, for each child, we obtained scores on executive control tasks that measure the updating, inhibiting, and shifting ability. We found that, compared to TD children, the children with SLI performed poorer on all executive control tasks. Moreover, they were overall slower and made more errors in the noun-phrase production task. Additionally, the magnitude of the distractor and switch effects was larger for the SLI than the TD group. Together, these results suggest that children with SLI have impaired language production and executive control abilities, and that the deficit in executive control influences the speed or accuracy of spoken noun-phrase production.

Introduction

Most children acquire their native language without difficulty, but in some children language does not develop normally. Specific language impairment (SLI) is a developmental disorder characterized by impaired language ability that cannot be explained by hearing, neurological, or intellectual deficit (e.g., Bishop, 2006; Evans, 2010; Leonard, 2014). SLI is a heterogeneous condition that varies in severity and domains of language being affected (i.e., phonological, morphological, lexical, syntactic, semantic, or pragmatic areas), see Leonard (2014) for a review. Compared to typically developing (TD) peers, children with SLI are at greater risk of poor academic, social, and emotional outcomes (e.g., St Clair, Pickles, Durkin, & Conti-Ramsden, 2011). Recent studies have shown that next to language problems, children with SLI also have deficits in nonlinguistic domains such as motor control (e.g., Finlay & McPhillips, 2013; Flapper & Shoemaker, 2013), response speed (e.g., Miller, Kail, Leonard, & Tomblin, 2001), procedural memory (e.g., Krishnan, Watkins, & Bishop, 2016; Ullman, 2004, 2016; Ullman & Pierpont, 2005), and executive control (e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Vissers, Koolen, Hermans, Scheper, & Knoors, 2015). It is possible that impairments in nonlinguistic domains cause or increase the language impairment. The present study examines this for executive control. Executive control is an umbrella term referring to the higher-order cognitive functions that regulate other cognitive processes, so as to remain goal-directed while facing distraction (for an overview, see Goldstein & Naglieri, 2014).

According to an influential proposal by Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000), executive control consists of at least three separable but related components: updating, inhibiting, and shifting (see also Friedman, Miyake, Young, De Fries, Corley, & Hewitt, 2008). Research examining deficits in executive control in SLI suggests impairment in some components of executive control but perhaps not in all (i.e., Henry et al., 2012; Im-Bolter et al., 2006). Children with SLI can have receptive (language comprehension) or expressive (language production) problems. The majority of children with SLI experience language production problems or language production combined with comprehension problems (e.g., Conti-Ramsden & Botting, 2006; Leonard, 2014). Considering that expressive impairment is most prevalent in SLI, it is important to better understand whether and how impairments in executive control abilities are present in the language production performance by children with SLI. To examine this was the aim of the study reported in the present article.

In the introduction, we first review previous findings on the relation between executive control and language production in adults, followed by findings on the executive control impairments in SLI. Next, we describe the behavioral paradigm that we used in the present study to examine executive control and language production in children with SLI and TD children. In the remainder, we report our study, in which we tested whether children with SLI are impaired in all or only some of the components of executive control, and whether they show corresponding impairments in a language production task. Finally, we discuss our findings and what they reveal about executive control and language production by typical and developmentally impaired children.

Influence of executive control on language production

According to an influential proposal by Miyake et al. (2000), executive control includes updating, inhibiting, and shifting abilities. Updating is the ability to temporarily maintain and manipulate information in working memory, and this ability determines working memory capacity (e.g., Ecker, Lewandowsky, Oberauer, & Chee, 2010). In the context of language production, the updating ability is involved in keeping in mind the communicative goals while scheduling conceptual and linguistic processes (e.g., Levelt, 1989; Piai & Roelofs, 2013). Inhibiting is the ability to lower the activation of unimportant or unwanted information (e.g., Aron, Robbins, & Poldrack, 2004). In language production, inhibition is applied to competing words that are co-activated together with the intended word (e.g., Shao, Roelofs, Acheson, & Meyer, 2014). Shifting is the ability to rapidly switch between tasks or types of information (e.g., Allport & Wylie, 2000; Monsell, 2003, 2015). In the context of language production, the shifting ability plays a role in switching between planning one utterance to planning another utterance (Sikora, Roelofs, Hermans, & Knoors, 2016), or to monitoring output.

Previous studies provided evidence that executive control influences language production in adults. The results of a number of studies suggest that updating ability (working memory capacity) influences the speed and accuracy of spoken language production (Hartsuiker & Barkhuysen, 2006; Klaus, Mädebach, Oppermann, & Jescheniak, 2017; Piai & Roelofs, 2013; Slevc, 2011). In examining the impact of updating, inhibiting, and shifting, Shao, Roelofs, and Meyer (2012) found in a picture naming study that participants' updating and inhibiting abilities were correlated with the speed of naming pictures, whereas no correlation was found for shifting. Sikora, Roelofs, Hermans, and Knoors (2016) demonstrated that all three components of executive control determined the speed of more complex language production by adults, namely noun-phrase production. We discuss this study and its design in some detail because we used the same design in the present study on children.

In their study, Sikora, Roelofs, Hermans, and Knoors (2016) measured the updating, inhibiting, and shifting abilities of adult participants using standard tests of executive control. Moreover, participants had to describe pictures of simple objects presented simultaneously with spoken distractor words. Pictures were line drawings presented in color or without a color. In response to the black-and-white pictures, participants had to produce *short* phrases consisting of an article and a noun (e.g., "the glass"), and in response to the colored pictures, participants had to produce *long* phrases consisting of an article, a color adjective, and a noun (e.g., "the red glass"). The updating ability was assumed to be more strongly involved in the production of the long than of the short phrases, given that for these long phrases more information has to be maintained and manipulated in working memory. Sikora et al. found that the magnitude of the difference in response time (RT) between short and long phrases, the *length effect*, was correlated with the participants' updating ability. Moreover, the spoken distractor words presented simultaneously with the pictures could be either *congruent* (the same as the picture name) or *incongruent* (different from the picture name). It was assumed that the inhibiting ability should be more strongly involved on the incongruent than on the congruent trials. It was found that the magnitude of the difference in RT between congruent and incongruent trials, the *distractor effect,* was correlated with the participants' inhibiting ability. Furthermore, two black-and-white pictures were followed by two colored pictures, and vice versa. It was assumed that the shifting ability should be more strongly engaged on *switch* trials (a picture preceded by a different picture type, such as a black-and-white picture preceded by a colored picture) than on *repeat* trials (a picture preceded by the same picture type). Sikora et al. found that the magnitude of the difference in RT between switch and repeat trials, the *switch effect*, was related to the participants' shifting ability. Moreover, in a subsequent EEG study using the same design, Sikora, Roelofs, and Hermans (2016) found that engagement of the updating, inhibiting, and shifting abilities during noun-phrase production was reflected in the N200 and P300 components of the event-related brain potential. These electrophysiological findings corroborate the tenet that the correlations between executive control abilities and corresponding RT effects in noun-phrase production reflect actual engagement of the executive abilities in language production. These studies provide evidence that in adults, executive control influences language production.

Executive control in SLI

A growing number of studies have shown that next to linguistic difficulties, children with SLI demonstrate impairment in executive control abilities. Different aspects of executive control have been investigated with various tasks and different age groups. However, the results of the previous studies are not always consistent. Below, we briefly review findings for the updating, inhibiting, and shifting abilities in children with SLI.

The updating ability has received perhaps the most interest in the literature. Accumulating evidence suggests that children with SLI have a working memory deficit, in the verbal domain and presumably also in the nonverbal domain. Impaired verbal updating ability has been found in pre-school children (e.g., Chiat & Roy, 2007; Petruccelli, Bavin, & Bretherton, 2012; Vissers et al., 2015) as well as in school-aged children (e.g., Archibald & Gathercole, 2006a; Freed, Lockton, & Adams, 2012; Montgomery, Magimairaj, & Finney, 2010). In contrast, studies examining nonverbal updating ability in SLI show conflicting results. Some studies demonstrated a deficit in nonverbal updating ability for SLI (e.g., Henry et al., 2012; Vugs, Hendriks, Cuperus, & Verhoeven, 2014) while several other studies failed to find differences between SLI and TD children (e.g., Archibald & Gathercole, 2006b; Lum, Conti-Ramsden, Page, & Ullman, 2012). However, a meta-analysis conducted by Vugs, Cuperus, Hendriks, and Verhoeven (2013) suggests that impairment in updating ability extents to the nonverbal domain. Moreover, a study by Henry et al. (2012) found differences in both verbal and nonverbal updating ability between SLI and TD groups after controlling for nonverbal IQ, and differences in nonverbal updating ability even after controlling for verbal IQ. These findings suggest that poorer performance on tests of nonverbal updating ability in SLI does not result from a deficit in verbal ability but that it is reflecting a domain-general updating deficit. In addition to the behavioral results, ratings by parents and teachers on the Behaviour Rating Inventory of Executive Function (BRIEF) add to the evidence that children with SLI have difficulties in updating ability, although verbal and nonverbal domains are not distinguished here (Cuperus, Vugs, Scheper, & Hendriks, 2014; Kuusisto, Nieminen, Helminen, & Kleemola, 2016).

Inhibiting ability deficits have also been identified for children with SLI. Several studies found that children with SLI perform poorer than TD children on various tasks that measure inhibiting ability (e.g., Henry et al., 2012; Im-Bolter et al., 2006; Spaulding, 2010; for a review, see Vissers et al., 2015). Moreover, Victorino and Schwartz (2015) demonstrated that performance of children with SLI on an auditory distraction task was impaired regardless of whether a distractor was related or unrelated to the target stimuli. This suggests that children with SLI may have a more broader problem with distractor processing, related or not related to the task. Additionally, BRIEF scores support this conclusion, showing that both teachers and parents rate children with SLI as having problems with inhibiting (Cuperus et al., 2014; Vugs et al., 2014; but see Kuusisto et al., 2016, who found no difference in ratings between SLI and TD groups).

The shifting ability in SLI has been less extensively investigated than other executive control components and studies on shifting offer perhaps the most inconclusive findings. While some studies have not found evidence for impaired shifting ability in children with SLI (Henry et al., 2012; Im-Bolter et al., 2006), other studies examining pre-school children demonstrated that the SLI group performed poorer than controls on behavioral shifting tasks (Farrant & Maybery, 2012; Roello, Ferretti, Colonnello, & Levi, 2015; for a review, see Vissers et al., 2015). Additionally, BRIEF studies suggests that children with SLI show deficits in shifting ability (Kuusisto et al., 2016; Vugs et al., 2014). However, in a recent review, Kapa and Plante (2015) concluded that there is not enough evidence to claim that children with SLI are impaired in shifting ability (but see Vissers et al., 2015).

Taken together, extant behavioral studies demonstrate that children with SLI are impaired in verbal updating ability as well as in inhibiting ability, with somewhat less consistent findings on nonverbal updating ability and no consistent evidence for an impairment in shifting ability. Additionally, behavioral ratings of parents and teachers suggest that children with SLI have deficits in all components of executive control.

Although some previous studies have examined the engagement of executive control in language performance, most of the studies did not examine all three components of executive control simultaneously. Also, most of the studies have concentrated on language comprehension (e.g., Montgomery, 1995, 2002a, 2002b, 2004; Montgomery & Windsor, 2007; Montgomery & Evans, 2009), and little is known about language production. To further investigate executive control and language production difficulties in SLI, we conducted a study in which we tested children with SLI and TD children on executive control tasks to see whether the children with SLI show deficits in all or only some of the executive control components. Additionally, we assessed their performance on a noun-phrase production task, as previously used in adult studies (Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016), to investigate whether all or only some of the executive control components show differences in the language production performance between children with SLI and TD children. Previous studies that examined whether executive control differences are present in language comprehension performance have looked at accuracy (Montgomery, 1995, 2002a, 2002b, 2004; Montgomery & Windsor, 2007; Montgomery & Evans, 2009). In the present study, we measured RTs in addition to accuracy.

Outline of the present study

In the current study, we tested children with SLI and TD children on four behavioral tasks measuring executive control abilities. We used an operation-span task to assess verbal updating ability, an odd-one-out task to measure nonverbal updating ability, a stop-signal task to measure inhibiting ability, and an emotion-gender switching task to measure shifting ability. We expected children with SLI to demonstrate lower scores on all four executive control tasks. Moreover, we measured children's speed and accuracy using a picture description task and a picture-word interference paradigm, as in our previous studies on adults (Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016). We measured errors and RTs in noun-phrase production, and assessed length, distractor, and switch effects, which reflect the updating, inhibiting, and shifting abilities. We expected children with SLI to have overall lower accuracy as well as to be slower across all conditions. Moreover, we expected that executive control difficulties in SLI will be manifest in the magnitude of the length, distractor, and switch effects in noun-phrase production. Therefore we expected children with SLI to have larger length, distractor, and switch effects compared to TD children.

Method

Participants

Seventy-four children participated in the experiment: 33 SLI (mean age 10;1 years) and 41 TD (mean age 10;7 years). Age did not differ significantly between groups, $t = -1.9$, $p > .05$. All children were native Dutch speakers and attended elementary school in the Netherlands. The children with SLI were recruited from schools for special education of Royal Dutch Kentalis, and TD children were recruited from regular elementary schools. All children were tested at the schools during school hours.

Procedure and design

Parents of the children were given information about the purpose of the study and were asked to sign a written consent form. Children participated in three experimental sessions and completed all the tasks in the same order (cf. Friedman et al., 2008; Miyake et al., 2000). In the first session, they performed the picture description task, in the second session the odd-one-out task and the emotion-gender switching task, and in the third session the stop-signal task, the operation-span task, and the Raven's Colored Progressive Matrices test. The three sessions together lasted about two hours per child. Additionally, TD children participated in a fourth session to complete the Clinical Evaluation of Language Fundamentals (CELF) test. The CELF scores of children with SLI were obtained from language therapists at the schools.

Picture-description task. In this task, the children had to describe a picture presented in the middle of a computer screen while trying to ignore a spoken distractor word that was played via headphones. Each trial began with a spoken distractor word and a picture presented with the same onset. The picture remained on the screen for 300 ms followed by a blank screen for 3500 ms. Each picture was presented with a congruent or an incongruent distractor word. Each distractor was presented an equal number of times in the experiment. The stimulus list was randomized using the program Mix (Van Casteren & Davis, 2006) with the restriction that stimuli were not repeated on consecutive trials. To focus on the influence of executive control and to reduce variance due to differences in processing speed among pictures and words, only a limited number of objects and colors were used. The set of stimuli consisted of four pictures, namely a couch, a lamp, a cupboard, and a chair, and four spoken distractors, which were the names of these objects. All spoken distractors were monosyllabic Dutch words: *bank* (*couch*), *lamp* (*lamp*), *kast* (*cupboard*), and *stoel* (*chair*). The words were all semantically related (like in the color-word Stroop task, e.g., Roelofs, 2003). The spoken words were recorded by a female native speaker of Dutch. There were two practice blocks and five experimental blocks of trials. Each experimental block consisted of 32 trials. In total there were 160 trials.

The pictures were either black-and-white line drawings or colored line drawings, either blue or red. The children were instructed to produce determiner-noun phrases (e.g., "de kast") when the presented picture was a black-and-white drawing (the short phrase condition). When the picture was presented in one of the two colors, the children had to produce a phrase that included an article, a color adjective, and the name of the object (e.g., "de blauwe kast", the long phrase condition). All picture names had the same grammatical gender in Dutch so that the determiner was always the definite article “de”. The number of trials for the short-phrase and long-phrase conditions was the same. The pictures were presented such that the required phrase type changed every second trial. Thus, in the trial sequence, two black-and-white pictures were followed by two colored pictures, which were followed by two black-and-white pictures, etc. This designed allowed us to measure picture description accuracy and RTs on repeat and switch trials. The number of trials for the repeat and switch conditions was equal.

Odd-one-out task. The odd-one-out task measures nonverbal updating ability (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). The odd-one-out task consisted of 42 triples of drawings representing arbitrary shapes. For each triple, two shapes were identical and one was different. The three figures were presented on the computer screen and children were instructed to indicate by pressing one of three buttons which figure is different from the others (i.e., the odd-one-out). The left button denoted the left figure, the middle button denoted the middle figure, and the right button denoted the right figure. Moreover, children were told to remember the location of the odd-one-out figure on each trial. After a number of trials varying between two and five, children had to recall the location of all odd-one-out figures since the beginning of a set. To this end, a table with three columns was presented on the computer screen. Each column referred to the three locations and the rows referred to the trials. Children indicated the recalled locations of the odd-one-out figures in the table, in the correct order, by sequentially pressing the corresponding buttons. This was followed by a next set of new figures.

Operation-span task. The operation-span task measures verbal updating ability (Conway et al., 2005). The operation-span task consisted of 27 mathematical operations and 27 Dutch words. Materials were presented on the computer screen. Each trial began with a fixation cross presented for 800 ms followed by a mathematical operation and a word presented in the middle of the screen (e.g., 5-4=3? *Flower*). Children were instructed to read aloud the mathematical operation and the word. Next, children had to indicate by a button press whether the mathematical operation was correct. After a random number of trials, varying between two and six, the children had to recall all words presented since the beginning of a set. The command “which words?” displayed on the screen indicated that children had to recall verbally all words in the correct order. This was followed by a new set of mathematical operations and words.

Stop-signal task. The stop-signal task measures nonverbal inhibiting ability (Verbruggen, Logan, & Stevens, 2008). The task consisted of 75% "go" trials and 25% "stop" trials. Each go trial began with a fixation point presented in the middle of the screen for 250 ms, followed by a target stimulus. The target stimulus was either a square or a circle. Children were instructed to respond to the stimuli by pressing one button (labeled "?") when they saw a circle and another button (labeled "Z") when they saw a square. The stimuli remained on the screen until the children responded but not longer than for 1250 ms. Children were told to respond to the stimuli as quickly and accurately as possible. On the stop trials also an auditory stimulus was presented. The auditory stimuli followed the visual stimuli. Children were instructed to inhibit their response to the visual stimuli on the trials when the auditory stimuli were presented. First the auditory stimuli were presented 250 ms after onset of the visual stimuli (the stop-signal delay). After each successful stop trial, the stop-signal delay was increased with 50 ms, while after each unsuccessful stop trial the stop-signal delay was decreased with 50 ms. The task consisted of one practice and three experimental blocks. The practice block included 32 trials and each experimental block included 64 trials.

Emotion-gender switching task. We modeled the emotion-gender switching task after the shape-color task that measures nonverbal shifting ability (Miyake et al., 2000). The task consisted of visual stimuli presented in the middle of the computer screen and a task cue presented below the stimuli. The stimuli consisted of a set of four pictures presenting girl and boy faces (indicated by the hair style), either happy or sad (indicated by the shape of the mouth). Children were instructed to respond to the gender or to the emotion of the presented faces. The task cue underneath the picture was a smaller picture of two faces depicting either the genders or the emotions. The task cue reminded the children of the task to be performed on the stimuli. Children were instructed to respond to the gender of the face when the task cue was a picture of girl and boy faces (emotion neutral), and to respond to the emotion when the presented task cue was a picture of happy and sad faces (gender neutral, i.e., a face without hair). Children had to press a right button as a response to the pictures depicting either a girl or a sad face, and they had to press a left button as a response to the picture depicting either a boy or a happy face. There were three practice blocks and two experimental blocks. In the first practice block children had to respond only to the gender of the face. In the second practice block children had to respond only to the emotion of the face. In the last practice block, two trials required a response to the gender of the face followed by two trials that required a response to the emotion of the face. Both experimental blocks were mixed-task blocks and consisted of 128 trials. In the mixed blocks, the task changed every second trial.

Raven's Colored Progressive Matrices. The Raven's Colored Progressive Matrices is a standard test to measure nonverbal intelligence in children under 12 years old (Van Bon, 1986). The test consists of three subtests, each including 12 trials. On each trial children were presented with a figure with a missing element and six or eight smaller figures that could complete the pattern. Children were instructed to point to the small figure that according to them completes the pattern the best.

Clinical Evaluation of Language Fundamentals (CELF) test. The CELF test assesses expressive and receptive language abilities (Kort, Schittekatte, & Compaan, 2008). In our study children completed three subtests of the Dutch version of the CELF (i.e., the CELF-4-NL): (1) Understanding and following instructions (BAV), (2) formulating sentences (ZF), and (3) vocabulary knowledge consisting of receptive (REC) and expressive (EXP) subtests. All materials were presented using the CELF test book. The BAV subtest measures the ability of children to understand and follow instructions. The test consists of 60 pictures. Each picture depicts a number of objects. Children sat in front of the experimenter and were asked to look at the pictures. The experimenter named a couple of objects and the children were instructed to point to the named objects in the correct order. The ZF subtest measures the expressive grammatical skills of children. The test consists of 20 pictures depicting various situations (e.g., children riding bicycles). Each picture is paired with a word. Children were asked to describe each picture with one sentence that had to include the word that was paired with the picture. The REC and EXP subtests measure the receptive and expressive vocabulary of children. Each subtest consists of 20 trials, each including 4 words. The experimenter read aloud the words. Children were instructed to select two words that shared something in common (e.g., *dark*, *warm*, *soft*, *cold*; the correct answer is *warm* and *cold*). After they identified two common words they were asked to justify their answer (e.g., *warm* and *cold* both describe the weather).

Data analysis

Picture-description task. Responses were categorized as errors if the produced phrase did not match the correct phrase, when the response included any kind of disfluency, was not initiated within 1000 ms, or was not completed before the end of a trial. Mean error rate was calculated for six conditions: long phrase, short phrase, congruent, incongruent, repeat, and switch. Repeated measures ANOVAs were conducted to test for main effects and interactions. Three main effects were defined: *length* (short vs. long phrase), *distractor* (congruent vs. incongruent), and *switch* (repeat vs. switch trials) treated as within-participant factors, and *group* (SLI vs. TD) as between-participant factor.

Additionally, we calculated RTs for each of condition. Responses were excluded from the RT analysis if an error occurred on a trial, as defined above. As in the error analysis, we calculated mean RTs for long phrase, short phrase, congruent, incongruent, repeat, and switch trials. Repeated measures ANOVAs were conducted to test for main effects of length, distractor, and switch, and for interactions between these within-participant factors. Again, group (SLI vs. TD) was entered into the analysis as between-participant factor.

Odd-one-out task. Scores for the odd-one-out task were calculated following the guidelines of Conway et al. (2005). The number of correctly recalled locations of the odd figures in a set was calculated. The number of figures in a set varied between two and five. The children received 1 point for each correctly recalled set. There were in total 12 sets. Thus, the total scores could range between 0 and 12. The score for each set was calculated as the proportion of the correctly recalled locations and the total number of locations to be recalled within the set. For example, correctly recalling the locations of two odd figures of a set of six figures was scored as 0.33 point, while correctly recalling the locations of two odd figures of a set of four figures was scored as 0.5 point. Higher total scores on the odd-one-out task indicate better nonverbal updating ability.

Operation-span task. Scores for the operation-span task were also calculated following the guidelines of Conway et al. (2005). The scores of two children were excluded from the analysis as one child had lower than 85% accuracy for the mathematical operations and another child did not correctly follow the instructions. The number of correctly recalled words for each set was calculated. The number of the words in each set varied between two and six. In total there were nine sets. Children received 1 point for each correctly recalled set, hence the total score could range between 0 and 9. The score for each set was calculated as the proportion of the correctly recalled words and the total number of words to be recalled within the set, similar to the scoring of the odd-one-out task. Higher total scores for the operation-span task indicate better verbal updating ability.

Stop-signal task. Scores were calculated following the instructions of Verbruggen et al. (2008). The data of three children were excluded from the analysis because of poor performance. The stop-signal reaction time (SSRT) was calculated for each child. The SSRT is equal to the difference between the mean RT of all go-trials and the mean stop-signal delay. Smaller SSRTs indicate better inhibiting ability.

Emotion-gender switching task. Trials were categorized as errors and excluded from the analysis if a participant failed to respond correctly to the presented figure. Mean RTs for the switch and repeat trials were calculated. The switching score was obtained by subtracting the mean RT for the repeat trials from mean RT for the switch trials. Smaller switching scores indicate better shifting ability.

Raven's Colored Progressive Matrices. The Raven's Colored Progressive Matrices test consisted of 36 trials. Children could receive 1 point for each correctly selected figure, hence the total score could range between 0 and 36. The raw scores were converted into standard scores following the guidelines of Van Bon (1986).

CELF test. We used the CELF guidelines to calculate scores for each subtest (i.e., BAV, ZF, REC, and EXP). In each subtest, children received 1 point for each correct answer. A total raw score for each subtest was calculated as the sum of all correct responses. The raw scores for each subtest were converted into standard scores based on the tables provided in the CELF manual (Kort et al., 2008).

Results

Executive control tasks

The mean scores for each of the executive control tasks for the SLI and TD groups are presented in Table 1. The table reveals that the children with SLI performed worse than the TD children on all the executive control tasks.

Table 1: Mean scores for the executive control tasks. The scores for the odd-one-out and operation-span tasks are proportion correct, and the scores for the stop-signal and emotion-gender switching tasks are latencies in milliseconds. SLI = specific language impairment; TD = typically developing.

Executive control task	SLI group	TD group
Odd-one out	.76	.85
Operation span	.38	.72
Operation span (no order)	.60	.80
Stop signal	331	248
Emotion-gender switching	231	91

Compared to TD children, the children with SLI had lower scores on the odd-one-out task, measuring nonverbal updating ability, $t = -4.10$, $p < .001$. Also, they performed poorer on the operation-span task, measuring verbal updating ability, both when the scores were calculated including all correctly recalled words, $t = -7.53$, $p < .001$, and when the scores were calculated including only the words that were recalled in the correct order, $t = -9.64$, $p < .001$. Moreover, children with SLI performed poorer than TD children on the stop-signal task, measuring inhibiting ability, as indicated by a larger magnitude of the SSRT, $t = 3.48$, $p < .001$. Finally, children with SLI had a larger switch effect than TD children on the emotion-gender switching task, representing shifting ability, $t = 2.62$, $p < .05$. The scores of the executive control tasks did not correlate among each other for both SLI and TD children, all ps > .05.

Raven's Colored Progressive Matrices

The SLI and TD groups did not differ significantly in their performance on the Raven test, measuring nonverbal intelligence, $t = -1.04$, $p = .30$. The mean score of the children with SLI was 6.6 and mean score of the TD children was 7.0.

CELF test

The SLI and TD groups differed significantly in language ability, as assessed by the Dutch version of the CELF. The children with SLI had lower scores on the BAV subtest (understanding and following instructions), $t = -6.15$, $p < .001$, lower scores on the ZF subtest (formulating sentences), $t = -8.21$, $p < .001$, and lower scores on the tests of vocabulary knowledge, both receptive (REC), $t = -5.54$, $p < .001$, and expressive (EXP), $t = -7.42$, $p < .001$. Thus, language ability was lower for the children with SLI than the TD children, whereas nonverbal intelligence (as assessed by the Raven test) did not differ. This is the canonical pattern (e.g., Leonard, 2014).

Picture-description performance

The mean error rate and mean RTs for each of the conditions of the picture-description task are presented in Table 2. The upper part of the table gives the results for the SLI group, the middle part gives the results for the TD group, and the lower part gives the results across groups.

Table 2: Mean error percentage (E%) and response time (RT) in the length, distractor, and switch conditions of the picture-description task for the SLI and TD Groups. SLI = specific language impairment; TD = typically developing.

			Switch					
Group		Distractor	Repeat		Switch		*Total*	
			E%	RT	E%	RT	E%	RT
	Length							
SLI	Short	Congruent	10	1045	13	1086	12	1065
		Incongruent	30	1231	37	1283	34	1257
		Total	25	1138	20	1185	23	1161
	Long	Congruent	21	1020	25	1034	23	1027
		Incongruent	33	1161	39	1128	36	1145
		Total	27	1091	32	1081	30	1086
	Total	Congruent	16	1032	19	1060	17	1046
		Incongruent	32	1196	38	1205	35	1201
		Total	24	1114	28	1133	26	1124
TD	Short	Congruent	2	844	3	859	2	852
		Incongruent	9	946	8	970	8	958
		Total	5	895	5	914	5	905
	Long	Congruent	6	886	10	875	8	880
		Incongruent	14	976	19	961	17	968
		Total	10	931	15	918	12	924
	Total	Congruent	4	865	6	867	5	866
		Incongruent	12	961	14	965	13	963
		Total	8	913	10	916	9	914
Total	Short	Congruent	6	944	8	973	7	959
		Incongruent	22	1089	19	1126	21	1108
		Total	13	1017	15	1050	14	1033
	Long	Congruent	13	953	17	955	15	954
		Incongruent	24	1068	29	1044	26	1056
		Total	19	1011	23	999	21	1005
	Total	Congruent	10	949	13	964	11	956
		Incongruent	22	1079	26	1085	24	1082
		Total	16	1014	19	1024	18	1019

Errors. Overall, the mean error rate was lower for the short than for the long phrases (length effect), $F(1, 72) = 25.16$, $MSE = .028$, $p < .001$, $\eta_p^2 = 0.26$, lower for the congruent than for the incongruent trials (distractor effect), $F(1, 72) = 283.12$, $MSE = .008$, $p < .001$, $\eta_p^2 = .80$, and lower for repeat than for switch trials (switch effect), $F(1, 72) = 37.25$, $MSE = .05$, $p < .001$, $\eta_p^2 = .34$. Moreover, a comparison between the SLI and TD groups revealed that the children with SLI had a significantly larger distractor effect (differences between congruent and incongruent trials of 18% error vs. 8% error, respectively), $F(1, 72) = 44.09$, $MSE = .08$, $p < .001$, $\eta_p^2 = .38$, and a significantly larger switch effect (differences between repeat and switch trials of 4% error vs. 2% error, respectively), $F(1, 72) = 4.22$, $MSE = .05$, $p < .05$, $\eta_p^2 = .055$. However, the magnitude of the length effect did not differ between the SLI and TD groups (the magnitude of the difference between short and long phrases was 7% error for both groups).

We obtained an interaction between length and distractor, $F(1, 72) = 4.14$, $MSE = .01$, $p < .05$, $\eta_p^2 = .054$. The length effect was larger on congruent than on incongruent trials. Moreover, there was an interaction of length, distractor, and group, $F(1, 72) = 11.49$, $MSE = .01$, $p < .001$, $\eta_p^2 = .14$. The children with SLI had a significant length effect on the congruent trials (the magnitude of the difference between the short and long phrases was 11% error), $t = -3.60$, $p < .001$, but not on the incongruent trials (2%), $t = .75$, $p = .46$, while the TD children had significant length effects on both congruent trials (6%), $t = 6.95$, $p < .001$, and on incongruent trials (9%), $t = 5.88$, $p < .001$. On the congruent trials, the magnitude of the length effect was larger for the children with SLI than the TD children (differences between short and long phrases of 11% error vs. 6% error, respectively), $t = 1.80$, $p < .05$.

Response times. Overall, mean RTs were shorter for the congruent than for the incongruent condition (distractor effect), $F(1, 70) = 90.91$, $MSE = 24623$, $p < .001$, $\eta_p^2 = 0.57$. Moreover, the children with SLI had a significantly larger distractor effect than the TD children (differences of 155 ms vs. 97 ms, respectively), $F(1, 70) = 4.71$, $MSE = 24623$, $p < .05$, $\eta_p^2 = .063$. Mean RTs were longer for the short than for the long phrases (length effect), $F(1, 70) = 3.93$, $MSE = 28127$, $p < .05$, $\eta_p^2 = .053$. This is in the opposite direction than expected. There was an interaction between length and group, $F(1, 70) = 11.22$, $MSE = 28127$, $p < .001$, $\eta_p^2 = 0.14$. The reverse length effect was obtained for the SLI group (RTs were longer on the short-phrase than on the long-phrase trials by 75 ms), $t = -2.85$, $p < .01$, but there was no significant length effect for the TD group (the difference between short-phrase and long-phrase trials was only 19 ms), $t = 1.55$, $p =$

.65. Moreover, we found an interaction between length and distractor, $F(1, 70) = 12.28$, $MSE = 6158$, $p < .001$, $\eta_p^2 = 0.15$. There was a significant reverse length effect on the incongruent trials, $t = 8.79$, $p < .001$, but there was no length effect on the congruent trials, $t = -.084$, $p = .933$. Moreover, there was an interaction of length, distractor, and group, $F(1, 70) = 4.48$, $MSE = 6158$, $p < .05$, $\eta_p^2 = 0.06$. The SLI group was slower in producing the short phrases than the long phrases on the incongruent trials (a reverse length effect of 112 ms), $t = -3.37$, $p < .001$, but there was no significant length effect on the congruent trials (a nonsignificant difference in RTs of 38 ms), $t = -1.44$, $p = .16$. The TD group, however, was faster in producing the short phrases than the long phrases on the congruent trials (a regular length effect of 28 ms), $t = 2.60$, $p < .01$, while there was no length effect on the incongruent trials (a difference of 10 ms), $t = 0.61$, $p = .55$. Finally, there was an interaction between length and switch, $F(1, 70) = 12.27$, $MSE = 5613$, $p < .001$, $\eta_p^2 = 0.15$. This interaction occurred because the switch effect was present for the short phrases, $t = -3.46$, $p < .001$, but not the long phrases, $t = -1.26$, $p = .21$. This interaction corresponds to that observed by Sikora, Roelofs, Hermans, and Knoors (2016) and Sikora, Roelofs, and Hermans (2016) for adult speakers.

General discussion

The purpose of this study was to examine whether, relative to TD peers, children with SLI show impairments in all three component abilities of executive control or only in some of these abilities, and whether impairments in all or only some of these executive abilities can be observed in their language production performance. We found that children with SLI show deficits in all three executive control abilities. Moreover, our result reveal that difficulties in executive control of children with SLI are present in their language production performance. Below, we first discuss our results for the four executive control tasks, followed by the results for the noun-phrase production task. Next, we discuss the consequences of our findings for the issue of executive control and language production by children with SLI and TD children.

Updating, inhibiting, and shifting abilities in children with SLI and TD children

We found significant differences between the SLI and TD groups for all four executive control tasks (i.e., odd-one-out, operation span, stop signal, and emotion-gender switching). These results suggest that children with SLI have deficits in verbal updating, nonverbal updating, inhibiting, and shifting abilities. These findings are consistent with previous studies that have shown that children with SLI exhibit limitations in verbal updating and inhibiting abilities (e.g., Henry et al., 2012; Im-Bolter et al., 2006; Victorino & Schwartz, 2015; Vugs et al., 2014). Moreover, our findings are in line with the results from the meta-analysis by Vugs et al. (2013), which showed that children with SLI are also impaired in nonverbal updating ability. Additionally, we obtained evidence that the shifting ability is impaired in SLI too. To our knowledge, only two previous behavioral studies demonstrated that SLI children are impaired in shifting ability (Farrant et al., 2012; Roello et al., 2015). The scores of the executive control tasks did not correlate among each other. This suggests that executive control abilities in both SLI and TD children are to some extent separable. Therefore, a poor score for one of the components of executive control cannot be explained by a poor score for another executive control component.

Kapa and Plante (2015) suggested that there is not enough evidence to conclude that children with SLI demonstrate a deficit in shifting ability. However, it is possible that the inconsistent results from previous studies are due to differences in processing demands of the tasks that have been used to assess shifting ability. It has been suggested that children with SLI have reduced processing resources or do not make effective use of available resources, which in turn might be reflected in their poor performance on executive control tasks (Im-Bolter et al., 2006). However, when processing required for a task is not really demanding, children with SLI seem to perform as well as TD children (Gathercole & Baddeley, 1990; Montgomery, 1995). In the two previous studies that demonstrated a shifting impairment in SLI, pre-school children were tested (Farrant et al., 2012; Roello et al., 2015). It is plausible that for this age group, the processing demands of the presented tasks were high enough to demonstrate deficits in shifting ability. However, for school-aged children, the same tasks might be not demanding enough to detect differences between SLI and TD groups. In line with this, Dibbets, Bakker, and Jolles (2006) observed in an fMRI study that although SLI and TD groups showed similar behavioral performance on a switching task, the children with SLI had an abnormal pattern of brain activity during task performance. More specifically, the children with SLI had additional activation in lateral frontal and cingulate areas, which are brain regions associated with executive control. It seems that the children with SLI had to recruit additional brain areas in order to perform behaviorally as well as the TD children. This would suggests that the children with SLI could only attain a normal level of behavioral performance by engaging compensatory mechanisms. However, it seems likely that full compensation is not possible if the processing demands of a task are really high. In the present study, we used a version of a shape-color switching task that is commonly used to test shifting ability in adults (e.g., Miyake et al., 2000; Sikora, Roelofs, Hermans, &

Knoors, 2016). Presumably, the processing demands of this task are higher than those of other tasks, such as the Trail Making task that has been used to test shifting ability in school-aged children with SLI (e.g., Henry et al., 2012). Perhaps the increased processing demand of our task allowed us to capture differences in shifting ability between SLI and TD groups.

To conclude, the findings of our study present evidence that children with SLI are impaired on the updating, inhibiting, and shifting abilities underlying executive control. Future studies may further investigate whether explicitly manipulating the processing demands of switching tasks results in performance differences between SLI and TD groups.

Executive control in language production by children with SLI and TD children

The second purpose of the present study was to examine whether problems in all or only some of the executive control abilities are reflected in the language production performance by children with SLI. To address this question, we used a noun-phrase production task to measure length, distractor, and switch effects, which relate to the updating, inhibiting and shifting abilities, respectively (Sikora, Roelofs, Hermans, & Knoors, 2016).

Across groups, we obtained length, distractor, and switch effects in the error rates, and a distractor effect in the RTs. These findings indicate that an increase in executive control demand has consequences for the speed and accuracy of noun-phrase production by children. This is in line with previous studies that demonstrated an impact of executive control on language production in adults (Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016). The current study extends those findings to children.

Although we did not obtain a main switch effect in the RTs, we did obtain an interaction between switch and length. In particular, we found a switch effect on the short-phrase trials but not on the long-phrase trials. These findings for children replicate our earlier results for adults (Sikora, Roelofs, Hermans, & Knoors, 2016; Sikora, Roelofs, & Hermans, 2016). In our earlier articles, we proposed that the asymmetrical switch effect arises because speakers have to prevent the tendency to inadvertently produce a short phrases (e.g., "the chair") in response to a colored picture requiring a long phrase (e.g., "the red chair"). This may be prevented by inhibiting the task set for short phrases or enhancing the task set for long phrases. In contrast, on trials with black-and-white pictures requiring a short phrase, prevention of the inadvertent production of a long phrase is not needed because the pictures only allow a short-phrase response. As a consequence, disengagement from the previous task set or overcoming previous inhibition of the now needed task set will take longer in switching to a short phrase than to a long phrase, which yields the asymmetrical switch effect that we observed both for adults and children.

Importantly, although length, distractor, and switch effects were obtained for both children with SLI and TD children, there were also differences between groups. First, we found that the children with SLI made overall more errors and had longer RTs than the TD children. Moreover, we found that the children with SLI had a larger distractor effect in errors and RTs and a larger switch effect in errors than the TD children. These findings demonstrate that children with SLI had more difficulty to overcome distractor interference and to switch between phrase types. The length effect in the errors did not differ between groups. However, we observed an interaction of length and distractor in both errors and RTs, which differed between groups. In particular, for the SLI group, there was a length effect in the errors on congruent trials but not on incongruent trials, whereas for the TD group, the length effect in the errors occurred on both congruent and incongruent trials. Moreover, for the SLI group, there was a reverse length effect in the RTs on incongruent trials, whereas for the TD group, no length effect was obtained in the RTs on incongruent trials and a regular length effect occurred on congruent trials.

A speculative account for the observed interaction of length, distractor, and group might be the following. In planning to say a short phrase on an incongruent trial, such as in planning to say "the chair" while hearing the incongruent distractor word "couch", children with SLI will experience a lot of interference from the incongruent distractor because of their inhibiting deficit (e.g., Henry et al., 2012; De Hoog, Langereis, Van Weerdenburg, Knoors & Verhoeven, 2015; Im-Bolter et al., 2006; Epstein et al., 2014; Roello et al., 2015; Spaulding, 2010). Given that "chair" is the first content word to be produced in the phrase, the incongruent distractor "couch" will much delay the response if a child wants to prevent an error. In planning to say the long phrase "the red chair" while hearing the incongruent distractor word "couch", interference will also occur, but now "chair" is the last content word to be produced in the phrase. This allows the children to start the production of "the red" while resolving the interference from the distractor "couch" during articulation of "the red". Distractor interference on short-phrase trails may prolong the RT such that it is longer than the RT on long-phrase trials, yielding a reverse length effect, as we observed. On congruent trials (e.g., hearing "chair"), there is no such interference, and a regular length effect is expected to be obtained. Instead, we observed a regular length effect in the error rates, and numerically (but not significantly), a reverse length effect in the RTs. This suggests that children with SLI are negatively affected even by congruent distractors, in line with the observations of Victorino and Schwartz (2015). Given that TD children have a better inhibiting ability than children with SLI, they are less influenced by distractor words (as revealed by their smaller distractor effect in the RTs and errors), and the difference in distractor impact between short-phrase and long-phrase trials will be less. As a consequence, regular length effects may be obtained in the RTs and errors, as we observed. To conclude, we obtained an interaction of length, distractor, and group. The interaction suggests that children with SLI are much more affected by distractor words than TD children, yielding a reverse length effect on incongruent trials for the SLI group.

Nature of the relation between executive control and language production deficits

Our results add to the evidence that deficits in nonlinguistic abilities such as executive control are reflected in the language performance of children with SLI. However, the directionality of the influence is not known yet. It is possible that (1) the executive control deficits in SLI contribute to the language impairment, (2) the language impairment in SLI contributes to the executive control deficits, or (3) a deficit in a third factor contributes to the deficits in both executive control and language (Bishop, Nation, & Patterson, 2014). The three possibilities are not mutually exclusive, and it remains possible, of course, that all three types of influences are present in SLI. We discuss each possible influence in the light of our present data.

Our findings are clearly compatible with the idea that the executive control deficits of children with SLI contribute to their language impairment. We found that children with SLI show impairment in all three components of executive control. Moreover, in phrase production, we found a larger magnitude of the distractor and switch effects for the children with SLI than the TD children (differences in the length effect between groups were more complicated). A plausible account would be that the increased demand of executive control on the incongruent and switch trials of the phrase-production task lowered performance for children with SLI because of their executive control deficit.

Our findings seem less compatible with the idea that the language impairment in SLI contributes to the executive control deficits. Several researchers have argued that language plays an important role in executive control (e.g., Goschke, 2000). In particular, it has been argued that executive control is facilitated by inner speech.

Most studies have concentrated on the role of inner speech in task switching, testing the idea that phonological representations may help switching between tasks (e.g., Emerson & Miyake, 2003). In particular, phonological representations may help in keeping track of the task sequence across trials (e.g., "shape, shape, color, …"), in retrieving the task goals from memory (e.g., word cues like "shape" and "color" indicating the target dimension), or in maintaining the stimulus-response mappings (e.g., "if red or circle, then press left key", "if blue or square, then press right key"). Evidence suggests that experimental manipulations of inner speech influence task switching performance, at least early in practice (for a review, see Monsell, 2015). This has been observed for both adults and children (Cragg & Nation, 2010). Moreover, Fatzer and Roebers (2012) examined the influence of inner speech on updating, inhibiting, and shifting in children (6-9 years old). The use of inner speech (phonological representations) was allowed in one condition and prevented by articulatory suppression in another condition. Fatzer and Roebers observed an influence of inner speech (i.e., by allowing phonological representations) on (verbal) updating, and to a lesser extent, on shifting, but there was no influence on inhibiting (but see Tullett & Inzlicht, 2010, for adults). The verbal updating task involved recalling a series of picture names. Note that the influence of preventing inner speech (i.e., articulatory suppression) on verbal updating comes as no surprise, because articulatory suppression will not only hamper the maintenance of phonological representations for executive control, but also the maintenance of the picture names. Taken together, these findings suggest that language (i.e., inner speech) may have an influence on shifting, and perhaps on updating, in adults and children.

In the present study, we found that the children with SLI were worse than the TD children on all four executive control tasks (i.e., odd-one-out, operation span, stop signal, and emotion-gender switching), assessing the updating, inhibiting, and shifting abilities. The findings for updating and shifting are in line with the idea that the children with SLI do worse than TD children on the executive control tasks because their language impairment negatively influences their executive control performance. That is, children with SLI may have been less good in using phonological representations to keep track of the task sequence across trials in the emotion-face switching task (e.g., "emotion, emotion, face, …"), in retrieving the task goals from memory (e.g., "emotion" and "face" indicating the target dimension), or in maintaining the stimulus-response mappings (e.g., "if girl or sad, then press right key", "if boy or happy, then press left key"). However, it is less clear how phonological representations may have helped the performance in the odd-one-out and operation-span tasks. Moreover, the results of Fatzer and

Roebers (2012) suggest that inner speech does not help inhibiting performance, but we observed that children with SLI performed worse on the stop-signal task than TD children. To conclude, previous studies suggest a role for inner speech in shifting and perhaps in updating, but not in inhibiting. Given that we observed group differences for shifting, updating, as well as inhibiting, our results suggest that differences in language ability (i.e., inner speech) can explain only some of the differences in executive control between groups.

We observed that the magnitude of the distractor and switch effects in the noun-phrase production task was larger for the children with SLI than the TD children. It is not so clear how phonological representations for executive control information may have helped performance on the phrase-production task. Compared to previous studies examining the role of inner speech in task switching, the present task seemed more natural. First, there were no arbitrary stimulus-response mappings that had to be learned (i.e., no arbitrary left or right button presses) but spoken responses, which were naturally associated with each picture (e.g., the response "the red chair" to a red chair). There was no need to maintain phonological representations of the stimulus-response mappings, such as "if chair and red, then say 'the red chair'" or "if chair and green, then say 'the green chair'". Instead, the language production system itself is highly experienced in achieving the required stimulus-response mappings. Second, the stimuli naturally invited one of the two tasks without the need for cueing the tasks. In particular, the colored pictures required a noun phrase that included a color adjective, whereas the black-and-white picture required a noun phrase without a color adjective (because the picture lacked color). Thus, there was no need to maintain task cues as a phonological representation in memory (e.g., "long phrase" or "short phrase"). Also, there was no need for using phonological representations to keep track of the task sequence across trials (e.g., "long phrase, long phrase, short phrase, …"). Even more, evidence suggests that maintaining phonological representations has detrimental effects on sentence planning (Klaus et al., 2017), and it is plausible that maintaining phonological representations of task information also hampers the planning of noun phrases. To conclude, it seems unlikely that inner speech (i.e., phonological representations of task information) has helped performance on the phrase production task. As a consequence, the poorer performance on the phrase-production task by children with SLI than TD children is unlikely due to possible differences in inner speech. Future research may examine this further.

Although our results suggest that the executive control difficulties in SLI influence their language production and perhaps not vice versa, it cannot be excluded that a deficit in a third factor contributes to the impairments in both executive control and language, at least partly. It has been argued that executive control and language production both draw on a procedural system (e.g., Roelofs, 2003, 2008, 2014; Roelofs & Piai, 2011). Moreover, it has been argued that children with SLI have a deficit in the procedural system (Krishnan et al., 2016; Ullman, 2004, 2016; Ullman & Pierpont, 2005), which is assumed to negatively affect language performance. Evidence suggests that children with SLI underperform on procedural learning tasks and show abnormalities in brain structures crucial for procedural memory (Krishnan et al., 2016; Lum et al., 2012; Ullman & Pierpont, 2005). If executive control and language performance both depend on the procedural system, and if this system is deficient in SLI, then both executive control and language performance are expected to be impaired in SLI. This would account for our present results. A procedural deficit would explain why the children with SLI performed worse than the TD children on the language comprehension and production tasks of the CELF, why they were overall slower and made more errors on the noun-phrase production task, why they performed worse on the executive control tasks testing for verbal and nonverbal updating, inhibiting, and shifting abilities, and why they showed larger effects in noun-phrase production.

To conclude, the present findings are more in line with the idea that executive control influences language function than the other way around. It is possible that the executive control and language deficits in SLI are due to a common third factor, at least partly. If executive control and language performance both draw on a procedural system, and this system is deficient in SLI, then this would explain the present results. Interestingly, Vugs, Knoors, Cuperus, Hendriks, and Verhoeven (2016) found a long lasting improvement of executive control by training of the updating, inhibiting, and shifting abilities in children with SLI. Further research may examine whether training of executive control improves language production in SLI and whether it has enduring effects.

Summary and conclusions

Previous studies demonstrated that children with SLI are impaired in verbal updating ability as well as in inhibiting ability, with somewhat less consistent findings on nonverbal updating ability and no consistent evidence for an impairment in shifting ability. In the present study, we found that, compared to TD children, children with SLI performed worse on executive control tasks testing for verbal as well as nonverbal updating, inhibiting, and shifting abilities. Moreover, previous studies showed that impaired executive control, in particular the updating ability, is reflected in the accuracy of language comprehension performance of children with SLI, but little is known about their production and the other executive control abilities. In examining both the speed and accuracy of language production performance, we observed that children with SLI were overall slower and made more errors than TD children in a noun-phrase production task. Moreover, the magnitude of the distractor and switch effects was larger for the SLI than the TD group (differences in the length effect between groups were more complicated). Together, these results suggest that children with SLI have impaired language production and executive control abilities, and that the deficit in executive control influences the speed or accuracy of spoken noun-phrase production. We argued that these findings suggest that the executive control deficit contributes to the language impairment rather than the other way around, and that it is possible that the executive control and language deficits in SLI are due to a common procedural system deficit, at least partly. Further research may investigate whether training of the updating, inhibiting, and shifting abilities would be beneficial for the language production performance of children with SLI.


LANGUAGE
PRODUCTION
UPDATING
INHIBITING
SHIFTING

CHAPTER 6

General discussion

In this dissertation, I investigated the relation between executive control and language production in typical and developmentally impaired speakers. Previous studies presented some evidence for the importance of executive control in spoken language production, more specifically, in the picture naming task (Shao, Roelofs, & Meyer, 2012; Piai & Roelofs, 2013). In the current thesis, I extended these findings and presented behavioral and electrophysiological evidence for the relation between executive control and noun-phrase production in adults and in children with and without language impairment.

In this last chapter, I first briefly describe the main findings of each chapter. This is followed by a discussion of the implications of these findings for our understanding of the relation between executive control and language production.

Main findings

Chapter 2 reports an RT study that investigated how individual differences in updating, inhibiting, and shifting abilities influence spoken noun-phrase production in healthy adults. The noun-phrase production task used in this study allowed us to measure the influence of all three components of executive control. This was achieved by using conditions with high and low demand on the updating, inhibiting, and shifting abilities. Individual differences in the performance between high and low demand conditions should reflect individual differences in the updating ability (length: long vs. short phrases), inhibiting ability (distractor: incongruent vs. congruent), and shifting ability (switch: switch vs. repeat). As expected, RTs were longer in the high-demand than in the low-demand conditions. This demonstrates that in healthy adults, an increase in executive control demand influences the speed of noun-phrase production. Moreover, we found that participants with better updating, inhibiting, and shifting abilities showed a smaller difference in RT between the high- and low-demand conditions. More specifically, we found that participants with better updating ability had a smaller length effect, those with better inhibiting ability had a smaller distractor effect, and those with better shifting ability had a smaller switch effect in the RTs. Finally, supporting previous evidence that updating, inhibiting, and shifting are to some extent separable abilities, there were no interactions between length, distractor, and switch, except that the switch effect depended on length. In particular, the switch effect in the RTs was present only for the short phrases. This indicates that switching to the short phrases was more demanding than switching to the long phrases, which we explained in terms of differential task-set inertia (e.g., Allport & Wylie, 1999, 2000). In producing the long phrases, the task set for the short phrases needs to be inhibited, and this inhibition needs to be overcome in switching to the short phrases, which prolongs the RT. The results of this first study indicate that updating, inhibiting, and shifting each influence the speed of phrase production, and they demonstrate a contribution of all three executive control abilities to language production.

Chapter 3 reports an ERP study that investigated whether electrophysiological components known to reflect updating, inhibiting, and shifting, can be identified during the planning of spoken noun-phrases. Earlier research in the literature has associated updating with the P300 and inhibiting and shifting with, respectively, anterior and posterior components of the N200. We replicated the behavioral results presented in Chapter 2. That is, we obtained length, distractor, and switch effects in the RTs, as well as an interaction between length and switch. Based on earlier evidence that the anterior N200 reflects inhibiting and the posterior N200 reflects shifting (Folstein & Van Petten, 2008; Verhoef, Roelofs, & Chwilla, 2010), we expected to obtain a distractor effect in the anterior N200 and a switch effect in the posterior N200. The ERP data revealed that the switch effect was present in a widely distributed N200 component, which suggests that switching between phrase types engaged both inhibiting and shifting. However, we failed to find a distractor effect in the N200. Additionally, we found a length effect in the anterior and in the posterior N200. The anterior N200 was larger for long than for short phrases while the posterior N200 was larger for short than for long phrases. Also, we obtained an interaction between the switch and the length effects in posterior quadrants: A posterior N200 switch effect was obtained for the short phrases but not for the long phrases. Moreover, we found a smaller P300 amplitude for the long than for the short phrases. This is in line with earlier evidence that an increase in updating demand reduces the P300 amplitude (Evans et al., 2011; Water et al., 2001). Additionally, we found a negative correlation between the length effect in the RTs and the P300 amplitude, which indicates that stronger engagement of the updating ability resulted in a smaller RT length effect. The second study provides electrophysiological evidence for the engagement of updating, inhibiting, and shifting in spoken noun-phrase production. Moreover, the results suggest that inhibiting and shifting of task set (reflected in the N200) occur before updating (reflected in the P300).

In Chapter 4, we further investigated the interaction in the RTs between length and switch that we obtained in Chapters 2 and 3. Asymmetrical switch costs have been often obtained in switching between tasks of different strength (e.g., Allport & Wylie, 1999, 2000). According to the task-set inertia account, the switch cost asymmetry can result from previous inhibition of the irrelevant task set, previous enhancement of the target task set, or both. In Chapters 2 and 3, we provided evidence that overcoming previous inhibition contributed to the switch cost asymmetry that we obtained. We tested this account by directly comparing switching in noun-phrase production and in the color-word Stroop task. In Experiment 1, using bivalent stimuli, we found asymmetrical costs for switching between long and short phrases and between Stroop color naming and reading. However, in Experiment 2, using bivalent stimuli for the weaker tasks (long phrases, color naming) and univalent stimuli for the stronger tasks (short phrases, word reading), we obtained an asymmetrical switch cost for phrase production, but a symmetrical cost for Stroop. These findings suggest that switching between phrase types involves overcoming previous inhibition, whereas switching between color naming and reading involves overcoming previous enhancement. Thus, the results confirmed our account of the switch cost asymmetry that we obtained for noun-phrase production in the previous chapters.

Chapter 5 reports a study that investigated the relation between executive control and language production in school-aged children with and without language impairment. We tested typically developing children (TD) and children with specific language impairment (SLI) on a number of tasks measuring the updating, inhibiting, and shifting abilities. Additionally, we measured their performance on the same noun-phrase production task that we used in Chapters 2, 3, and 4. We found that children with SLI perform worse than TD children on all executive control tasks. This shows that SLI children have difficulties in all three components of executive control. Importantly, we presented, for the first time, behavioral evidence that school-aged children with SLI are impaired in shifting ability. Moreover, we found that children with SLI had larger distractor and switch effects than TD children. These results suggest that children with SLI have impaired language production and executive control abilities, and that the deficit in executive control influences the speed or accuracy of spoken noun-phrase production.

Executive control and noun-phrase production in adults and children

The behavioral findings described in Chapters 2 and 3 demonstrate that in healthy adults, the updating, inhibiting, and shifting components of executive control influence the speed of noun-phrase production. These findings are consistent with previous studies that demonstrated that the speed of picture naming was determined by the updating and inhibiting abilities of speakers (Shao et al., 2012; Piai

& Roelofs, 2013). In this dissertation, I replicated and extended these results and presented evidence that not only updating and inhibiting but also shifting play a role in more complex forms of language production. Participants with better updating ability showed a smaller difference in RT between the production of complex and simple phrases, and those with better inhibiting ability showed a smaller difference in RT between incongruent and congruent spoken distractors. Additionally, the shifting ability influenced noun-phrase production. Previous studies investigating the relation between executive control and the speed of picture naming did not find evidence for a role of shifting ability (Shao et al., 2012). However, it is not clear how shifting ability would be involved in simple picture naming. In the noun-phrase production task used in this thesis, the shifting ability was more explicitly engaged. Participants had to switch between the short and the long phrases. RTs were longer on switch than on repeat trials, and participants with better shifting ability were more successful in switching between phrase types. This demonstrates that when switching is explicitly required, also the shifting ability influences the speed of spoken language production.

Additionally, we obtained evidence that executive control also plays a role in language production by children. The findings reported in Chapter 5 indicate that an increase in the demand on executive control has consequences for the speed or accuracy of noun-phrase production by TD children and children with SLI. First, we observed that compared to TD children, children with SLI underperformed on tasks measuring their updating, inhibiting, and shifting abilities. Second, the magnitude of the distractor and switch effects in noun-phrase production was larger for the SLI than the TD children. Thus, an increase in the demand on executive control in the noun-phrase production task had a larger effect on the accuracy or response speed for SLI children than for TD children. These findings suggest that children with SLI have impaired language production and executive control abilities, and that the deficit in executive control influences the speed or accuracy of spoken noun-phrase production.

Although it has also been proposed that language ability can play a role in executive control through inner speech (e.g., Emerson & Miyake, 2003; Fatzer & Roebers, 2012), our results are more in agreement with the claim that executive control ability influences language production rather than vice versa. First, studies investigating the importance of inner speech for executive control found that articulatory suppression hampered performance on updating and shifting tasks but not on inhibiting tasks. Therefore, poorer inner speech of children with SLI might account for their worse performance on our updating and shifting tasks, but it cannot explain their worse performance on our inhibiting task. Second, it is not clear how inner speech might contribute to performance on the noun-phrase production task. Thus, our findings are more in line with the assumption that executive control problems in SLI contribute to their language impairment rather than vice versa. Our findings leave open the possibility that a third factor influences both executive control and language production.

Taken together, the results of Chapters 2, 3, and 5 provide evidence that executive control is important for language production in both adults and children, and that difficulties in executive control contribute to language production problems.

Electrophysiology of executive control in noun-phrase production

Consistent with the behavioral findings presented in this dissertation, we also found electrophysiological evidence for the on-line engagement of executive control in language production. As expected, we found smaller a P300 for the long than for the short phrases. Modulation of the P300 component has been associated with demand on the updating ability (e.g., Kok, 2001; Polich 2007). Moreover, studies found that an increase in task complexity results in a smaller P300 amplitude (e.g., Evans et al., 2011; Kok, 2001; Polich, 2007). Therefore, our findings suggest that producing long phrases required greater engagement of updating ability. Additionally, we found that a larger length effect in the P300 was associated with a smaller length effect in the RTs. Stronger engagement of the updating ability seemed to result in better behavioral performance. These results provide further evidence that the updating ability influences noun-phrase production. Similarly, we obtained further evidence for a role of shifting and inhibiting. Although the electrophysiological results for these executive control abilities are less straightforward, they do suggest that inhibiting and shifting were engaged during the noun-phrase production. We found a widely distributed switch effect in the N200. In the literature, a distinction has been made between an anterior N200 associated with inhibiting and a posterior N200 associated with shifting (Folstein & Van Petten, 2008; Verhoef et al., 2010). Therefore, the switch effect obtained in the widely distributed N200 suggests that both inhibiting and shifting were engaged in switching between phrase types. Indeed, we obtained larger anterior N200 for the long than for short phrases what suggests that producing long phrases required more inhibition (of short phrases). This in line with the claim that in switching paradigms, performing a weaker task often requires stronger inhibition of the task set for the stronger task, whereas performing the stronger task requires little or no inhibition of the task set for the weaker task (e.g., Allport

& Wylie, 1999, 2000). Consequently, switching to the stronger task should be more demanding because of the previous inhibition that needs to be overcome. This is exactly what we observed: A switch effect in RTs and in the posterior N200 (associated with shifting) for the short phrases but not for the long phrases. These results provide evidence that, in addition to updating, also inhibiting and shifting are involved in spoken noun-phrase production. Our electrophysiological results also provide information on the dynamics of the involvement of the components of executive control. Our findings suggests that in producing a phrase, participants first engage their shifting and inhibiting abilities, as reflected by the anterior and the posterior N200, followed by the updating ability, as reflected by the P300. In other words, participants had to first inhibit the incorrect phrase type and switch to the correct one before they could start constructing the phrase.

Switch cost asymmetry in noun-phrase production

As discussed above, the shifting ability is important for noun-phrase production in adults and in children. Switching between phrase types resulted in slower responses and in poorer accuracy. However, we also found that this was the case only for the short phrases. We obtained switch costs in RTs and the posterior N200 for the short but not for the long phrases. This is in agreement with the task-set inertia account. Performing more the weaker task (i.e., long phrase production) requires enhancement of this weaker task and/or inhibition of the irrelevant stronger task. Consequently, it will be more difficult to switch to the stronger task because it requires overcoming of the previous enhancement of the other weaker task or the previous inhibition of the stronger task itself. However, given that bivalent stimuli were used for the stronger task in Chapters 2 and 3, it remained unclear whether previous enhancement, inhibition, or both contributed to the asymmetrical switch costs. Therefore, the experiments reported in Chapter 4 further examined the source of the asymmetrical switch costs. We tested this for our noun-phrase production task (involving switching between short and long phrases) and for the color-word Stroop task (involving switching between word reading and color naming). Using bivalent stimuli, we found asymmetrical costs for switching between long and short phrases and between Stroop color naming and reading. However, using bivalent stimuli for the weaker tasks (long phrases, color naming) and univalent stimuli for the stronger tasks (short phrases, word reading), we obtained an asymmetrical switch cost for phrase production, but a symmetrical cost for Stroop. These findings suggest that switching between phrase types involves overcoming previous inhibition, whereas switching between color naming and reading involves overcoming previous enhancement.

Conclusions

In this dissertation, I demonstrated that executive control influences spoken language production in healthy adults and in children with and without language impairment. Additionally, I identified inhibition as being the source of the asymmetrical switch costs in switching between long and short phrases. These findings have both theoretical and practical implications. First, they extend our knowledge about the relation between executive control and language production, showing that all components of executive control play a role. Second, these results may inform interventions for children with SLI. Future research may examine whether the training of executive control helps improve the language skills of children with SLI.


LANGUAGE
PRODUCTION
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APPENDICES

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Samenvatting

Het doel van dit proefschrift is om de relatie tussen executieve controle en taalproductie te onderzoeken, bij sprekers met en zonder ontwikkelingsstoornis. Eerder onderzoek wijst erop dat executieve controle belangrijk is voor de productie van gesproken taal. Toch zijn er nog een aantal vragen onbeantwoord. Om te beginnen is het onduidelijk hoe de drie componenten van executieve controle (bijwerken, onderdrukken en schakelen) gerelateerd zijn aan meer complexe vormen van taalproductie, zoals de productie van naamwoordelijke zinsdelen. En als het gaat om de impact van executieve controle op taalproductie, weten we maar weinig van de elektrofysiologische basis en dynamiek daarvan. Tot slot is het onduidelijk óf, en hoe, executieve controle gerelateerd is aan de taalproblemen die voorkomen bij ontwikkelingsstoornissen zoals taalontwikkelingsstoornis (TOS). Deze vragen heb ik onderzocht in dit proefschrift.

De zinsdeelproductietaak. In alle hoofdstukken heb ik een taak gebruikt die draait om de productie van naamwoordelijke zinsdelen. Hiermee kon ik de impact van executieve controle op gesproken taalproductie meten. De taak was steeds iets anders in elke studie. De proefpersonen moesten plaatjes beschrijven die in het midden van het computerscherm werden getoond. Daarbij hoorden ze gesproken woorden ('afleiders') die ze moesten negeren. De stimuli bestonden uit vier tekeningen van simpele objecten (bijv. een glas) en vier gesproken afleiders, namelijk de namen van deze objecten. De proefpersonen moesten alle plaatjes beschrijven met naamwoordelijke zinsdelen die een lidwoord bevatten (bijv. "het glas"). De namen van de plaatjes en van de gesproken afleiders konden ofwel twee identieke zelfstandig naamwoorden zijn (bijv. een plaatje van een glas en het gesproken woord *glas*) – dit was de congruente conditie – of twee verschillende zelfstandig naamwoorden (bijv. een plaatje van een glas en het gesproken woord *bord*) – dit was de incongruente conditie. Er werd aangenomen dat vermogen tot onderdrukken harder nodig was bij incongruente dan congruente trials, en dat de grootte van het verschil in reactietijd tussen de twee afleidertypes – het afleidereffect – iemands vermogen tot onderdrukken zou reflecteren. De plaatjes waren zwart-wit of gekleurd. De proefpersonen kregen de instructie om een lidwoord en zelfstandig naamwoord te produceren als ze een zwart-wit plaatje te zien kregen – dit was de korte-zinsdeel-conditie (bijv. "het glas"). Als ze een gekleurd plaatje zagen, moesten de proefpersonen een zinsdeel produceren bestaande uit een lidwoord, een kleur, en de naam van het object – dit was de lange-zinsdeel-conditie (bijv. "het groene glas"). Er werd aangenomen dat vermogen tot bijwerken harder nodig was bij de productie van lange dan van korte zinsdelen, en dat de grootte van het verschil in reactietijd tussen de zinsdeeltypes – het lengte-effect – iemands

Appendix

vermogen tot updating zou reflecteren. De plaatjes werden zo gepresenteerd dat het type zinsdeel dat geproduceerd moest worden, elk tweede trial veranderde. Twee zwart-witte plaatjes werden dus steeds gevolgd door twee gekleurde plaatjes, die weer gevolgd werden door twee zwart-witte plaatjes, etc. Dit maakte het mogelijk voor ons om de reactietijden m.b.t. het beschrijven van plaatjes te meten op herhaal- en wissel-trials. Er werd aangenomen dat vermogen tot schakelen harder nodig was bij wissel-trials, en dat de grootte van het verschil in reactietijd tussen de twee trialtypes – het wisseleffect – iemands vermogen tot schakelen zou reflecteren.

In **hoofdstuk 2** heb ik onderzocht hoe individuele verschillen wat betreft vermogen tot bijwerken, onderdrukken en schakelen van invloed zijn op de gesproken productie van naamwoordelijke zinsdelen bij volwassenen. Met deze productietaak was het mogelijk om de bijdrage van alle drie de componenten van executieve controle te meten, namelijk door condities te gebruiken die veel of weinig aanspraak maakten op iemands vermogen tot bijwerken, onderdrukken en schakelen. Individuele verschillen in prestatie tussen de condities met hoge en lage aanspraak zouden individuele verschillen reflecteren in het vermogen tot bijwerken (lengte: lange vs. korte zinsdelen), onderdrukken (afleiding: incongruent vs. congruent), en schakelen (wisseling: wisselen vs. herhalen). Zoals verwacht waren de reactietijden hoger in de condities met hoge dan met lage aanspraak. Dit laat zien dat, bij gezonde volwassenen, een toename in de aanspraak op executieve controle de snelheid beïnvloedt waarmee naamwoordelijke zinsdelen geproduceerd worden. We vonden ook dat het verschil in reactietijd tussen de condities met hoge en lage aanspraak kleiner was bij proefpersonen met betere vermogens tot bijwerken, onderdrukken en schakelen. Meer specifiek vonden we dat proefpersonen met betere vermogens tot bijwerken een kleiner effect van lengte vertoonden, proefpersonen met betere vermogens tot onderdrukken een kleiner effect van afleiding vertoonden, en proefpersonen met betere vermogens tot schakelen een kleiner effect van wisseling vertoonden. Tot slot waren er geen interacties te zien tussen lengte, afleiding en wisseling, behalve dat het effect van wisseling afhankelijk was van lengte. Dit ondersteunt eerder onderzoek waarin werd gevonden dat bijwerken, onderdrukken en schakelen tot op zekere hoogte onafhankelijke vermogens zijn. Wat betreft de interactie tussen wisseling en lengte was het effect van wisseling in de reactietijden alleen aanwezig bij korte zinsdelen. Dit laat zien dat wisselen naar een kort zinsdeel toe meer aanspraak maakt op vermogens dan wisselen naar een lang zinsdeel toe. Dit hebben we verklaard in termen van taakset-inertie (bijv. Allport & Wylie, 1999, 2000). Bij de productie van lange zinsdelen moet de taakset voor de korte zinsdelen onderdrukt worden (onderdrukken), en deze onderdrukking moet weer opgeheven worden als er gewisseld wordt naar een kort zinsdeel. Dit leidt tot een langere reactietijd. De resultaten van deze eerste studie laten zien dat bijwerken, onderdrukken en schakelen alle drie invloed uitoefenen op de snelheid waarmee zinsdelen geproduceerd worden. Elke component van executieve controle draagt dus bij aan taalproductie.

In **hoofdstuk 3** heb ik onderzocht of elektrofysiologische componenten waarvan we weten dat ze bijwerken, onderdrukken en schakelen reflecteren, aangetoond kunnen worden bij het plannen van gesproken naamwoordelijke zinsdelen. In eerder onderzoek is er een associatie gevonden tussen bijwerken en de P300, en tussen onderdrukken en schakelen met respectievelijk anterieure en posterieure componenten van de N200. Wij hebben de resultaten van het gedragsonderzoek uit Hoofdstuk 2 gerepliceerd. Met andere woorden, we hebben effecten gevonden van lengte, afleiding en wisseling in de reactietijden, en ook weer een interactie tussen lengte en wisseling. Op basis van eerdere evidentie dat de anterieure N200 onderdrukken reflecteert en de posterieure N200 schakelen (Folstein & Van Petten, 2008; Verhoef, Roelofs, & Chwilla, 2010), verwachtten we een effect van afleiding te vinden in de anterieure N200 en een effect van wisseling in de posterieure N200.

De ERP-data lieten zien dat het effect van wisselen aanwezig was in een breed gespreide N200-component. Dit suggereert dat zowel onderdrukken als schakelen betrokken zijn bij wisselen tussen zinsdeeltypes. Echter, we vonden geen effect van afleiding in de N200. We vonden ook een effect van lengte in de anterieure en posterieure N200. De anterieure N200 was groter voor lange dan voor korte zinsdelen, terwijl de posterieure N200 groter was voor korte dan voor lange zinsdelen. Daarbij vonden we ook een interactie tussen de effecten van wisseling en lengte in de posterieure kwadranten: er was een posterieur N200-effect voor wisseling als het aankwam op korte, maar niet op lange zinsdelen. We vonden ook een kleinere P300-amplitude voor de lange in vergelijking met de korte zinsdelen. Dit komt overeen met eerdere evidentie dat een verhoogde aanspraak op bijwerken leidt tot een kleinere P300-amplitude (Evans et al., 2011; Water et al., 2001). Tot slot vonden we een negatieve correlatie tussen het effect van lengte in de reactietijden en P300-amplitude. Dit laat zien dat een sterker gebruik van het vermogen tot bijwerken leidt tot een kleiner effect van lengte in reactietijden. De tweede studie levert elektrofysiologische ondersteuning voor het aandeel van bijwerken, onderdrukken en schakelen in de productie van gesproken naamwoordelijke zinsdelen. Bovendien suggereren de resultaten dat onderdrukken en schakelen van taakset (gereflecteerd in de N200) plaatsvinden vóór bijwerken (gereflecteerd in de P300).

In **hoofdstuk 4** hebben we nader onderzoek gedaan naar de interactie in reactietijd tussen lengte en wisseling, die we hadden gevonden in Hoofdstuk 2 en 3. Het is al vaker gevonden dat wisselen tussen taken met een verschillende sterkte tot asymmetrische 'wisselkosten' leidt (bijv. Allport & Wylie, 1999, 2000). Volgens de taakset-inertie kunnen de asymmetrische wisselkosten verklaard worden door eerdere onderdrukking van de irrelevante taakset, door een eerdere versterking van de doel taakset, of door beide. In Hoofdstuk 2 en 3 presenteerden we evidentie dat het te boven komen van eerdere onderdrukking bijdraagt aan asymmetrische wisselkosten. We hebben deze verklaring getest door wisseling in de productie van naamwoordelijke zinsdelen te vergelijken met wisseling in de kleur-woord Strooptaak.

In Experiment 1 maakten we gebruik van bivalente stimuli en vonden we asymmetrische kosten voor de wisseling tussen lange en korte zinsdelen, en tussen kleur benoemen en lezen in de Strooptaak. Echter, in Experiment 2, waarin we gebruik maakten van bivalente stimuli voor de zwakkere taken (lange zinsdelen, kleur benoemen), en van univalente stimuli voor de sterkere taken (korte zinsdelen, woorden lezen), vonden we asymmetrische wisselkosten voor zinsdeelproductie, maar symmetrische kosten voor de Strooptaak. Deze bevindingen suggereren dat het voor wisselen tussen zinsdeeltypes nodig is om eerdere onderdrukking te boven te komen, terwijl het voor wisselen tussen kleur benoemen en lezen nodig is om eerdere versterking te boven te komen. De resultaten bevestigen dus de verklaring voor de asymmetrische wisselkosten die we vonden voor zinsdeelproductie in de vorige hoofdstukken.

Hoofdstuk 5 beschrijft een studie waarin de relatie tussen executieve controle en taalproductie werd onderzocht, bij schoolgaande kinderen met en zonder een taalstoornis. We testten kinderen die zich typisch ontwikkelden en kinderen met een taalstoornis (TOS) op een aantal taken die de vermogens tot bijwerken, onderdrukken en schakelen maten. Ook maten we hun prestatie op dezelfde taak voor zinsdeelproductie die we gebruikten in Hoofdstuk 2, 3 en 4. We vonden dat kinderen met TOS slechter presteerden dan kinderen met een typische ontwikkeling, op alle taken die executieve controle maten. Dit laat zien dat kinderen met TOS problemen hebben met alle drie de componenten van executieve controle. Een belangrijk resultaat was ook dat we, voor het eerst in gedragsonderzoek, konden laten zien dat schoolgaande kinderen me TOS beperkt zijn in hun vermogen tot schakelen. We vonden ook dat kinderen met TOS grotere effecten vertoonden van afleiding en wisseling dan kinderen met een typische ontwikkeling. Deze resultaten suggereren dat kinderen met TOS beperkt zijn in hun taalproductie en vermogen tot executieve controle, en dat hun beperking in executieve controle invloed heeft op de snelheid en nauwkeurigheid van gesproken zinsdeelproductie.

In dit proefschrift heb ik laten zien dat executieve controle invloed heeft op de productie van gesproken taal bij gezonde volwassenen en bij kinderen met en zonder taalstoornis. Daarbij heb ik gevonden dat onderdrukken de bron is van de asymmetrische wisselkosten bij het wisselen tussen lange en korte zinsdelen. Deze resultaten hebben zowel theoretische als praktische implicaties. Ten eerste vergroten ze onze kennis over de relatie tussen executieve controle en taalproductie: alle componenten van executieve controle spelen daarbij een rol. Ten tweede kunnen deze resultaten informatief zijn als het gaat om interventies voor kinderen met TOS. Er is meer onderzoek nodig om vast te stellen of het trainen van executieve controle kan helpen om de taalvaardigheid bij kinderen met TOS te verbeteren.

Acknowledgment

Thank you all for the part you played in my journey to finish this thesis. I was very lucky to have had your words of wisdom, support and encouragement. Every piece of advice and kindness, big or small, helped me take the next step toward completing this work. For this, I am eternally grateful.

My supervisors: Prof. dr. Ardi Roelofs, Dr. Daan Hermans and Prof. dr. Harry Knoors, this thesis would not be possible without your mentorship. Thank you for your time and your insightful suggestions, but especially, thank you for believing in me and giving me the opportunity to work on this project. Ardi, you always had time for discussions, advice and my questions. I have benefitted so much from your knowledge and your feedback. Thank you for steering me in the right direction. Harry and Daan, my last study would not have been possible without your support. Thank you for remaining critical in our discussions and often reminding me about practical aspects of carrying out studies with children.

Prof. dr. Simon Fisher, thank you for your involvement and valuable suggestions in my first study.

Members of the manuscript committee, Prof. dr. Herbert Schriefers, Prof. dr. Ludo Verhoeven and Prof. dr. Elma Blom, thank you for spending time and effort to read and assess my thesis.

My early supervisor, Dr. Lorenza Colzato, thank you for your mentorship in the earliest phase of my research career but especially, thank you for believing in me.

My participants, especially all the children, thank you so much for your contribution, your time and your patience while naming the same picture over and over again.

My Donders friends and colleagues. Carmen and Sophie, you made me feel welcome from the very beginning and helped me to find my way around. Thank you for the two years filled with science and life discussions, lunch breaks, walks and so much more. Sophie, thank you for our meditation sessions. Carmen, thank you for your help with EEG. Marpessa and Johanna, it was so nice to share office with you. Johanna, thank you for all your hard work as my paranymph. Marpessa, thank you for our chats and for keeping me company when commuting by train. Xioachen, my most recent officemate, maybe we did not agree about many things (meat or veggies, cats or dogs) but it was definitely a pleasure to get to know you better. Thank you for keeping an eye on my desk, for all your help as my paranymph and for all fun chats we had. Kevin thank you for all the chats and words of comfort. Vitoria, thank you for your support with setting up my first study. Natalia, Fenny, Sybrine, Agnes, Magda, Simon and Annika, thank you for the chats and the friendly attitude, you all made my PhD time definitely nicer.

Technical and administrative support team. Miriam, thank you for all your help with my EEG study. Gerard and Pascal, thank you for your support with setting up my studies and especially thank you for your patience. Ronny, Vanessa, Maaike and Jolanda, thank you for your all your help and your kindness.

Donders Wonders team, it was a pleasure to work with you all!

My friends, I am so happy to have you all in my life. Walucha and Agata, my second family, thank you for your support through all those years. You were there for me from the very beginning of my scientific career, and even before it. Thank you for listening to my countless research ideas, for your feedback and especially for your love and encouragement. Your interest in my stories (even if not always genuine☺) kept the flame of scientific curiosity burning. Asia and Mart thank you for your friendship. Monika L, thank you for your listening ear. I hope you realise how valuable all your advice was. Divina, thank you for our talks and your encouragement. It often gave me the courage to keep going and to believe in myself. Iza, thank you for your contagious optimism. Tirza thank you for your friendship and your kindness. You have so often opened my eyes to see alternative solutions to a problem. Monika K, thank you for your friendship.

Sylvia, Sico and Eva. Thank you for your kindness, I was very lucky to get to know you. Sylvia, you were one of the first people to congratulate me on my PhD position, thank you for your interest and your support!

Family Cosijn (Heleen, Willem, Merel, Coen and Wieger) and Van der Ben (Gerjo, Ian, Sinie and Stijn), I have learned so much from you during my first years in the Netherlands. Dank jullie wel!

My family: Tato i Mama, dziękuję, za to że zawsze we mnie wierzyliście, nawet wtedy kiedy ja w siebie wątpiłam. Jesteście fundamentem mojego sukcesu. Mamo, dziękuję Ci za każdą minutę spędzoną ucząc mnie tabliczki mnożenia i ortografi. Dawid, dziękuję za piękny projekt mojej okładki. Klaudia, dziękuję Ci za bycie

super siostrą. Zosia, dziękuję za radość, którą przynosisz. Mamo i ciociu Iwono, dziękuję że znalazłeście czas, aby przebyć długą drogę do Nijmegen.

My love and my best friend, Şükrü, you kept believing in me even when I had my doubts. Thank you for keeping me company during this journey and for reminding me what matters most. Your support and your humour kept me sane.

Stella, thank you for your company while working toward my PhD.

Curriculum Vitae

Kasia Sikora was born in Tomaszów Mazowiecki, Poland, on 17 September 1984. After completing her secondary education in Poland, she arrived in the Netherlands and enrolled herself in Dutch Studies at Leiden University. She received her Propedeuse in 2006, and a year later she began a Bachelor in Psychology at Leiden University. After receiving her Bachelor degree in 2010, she attended a two year M.Sc. programme in cognitive neuroscience, also at Leiden University. For her M.Sc. thesis, she conducted research where she studied the relation between dopamine levels and conflict monitoring. During the two year research master programme she further developed a passion and interest for psychological research. In 2012, she started a PhD at the Donders Institute for Brain, Cognition and Behaviour at Radboud University in Nijmegen as supervised by Prof Ardi Roelofs, Prof Harry Knoors and Dr Daan Hermans. During her PhD, she studied the relation between executive control and language production in adults and in children using behavioural and electrophysiological methods.

Publications

Sikora, K., Roelofs, A., Hermans, D., & Knoors, H. (manuscript submitted). Executive control in language production by children with and without language impairment.

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ISBN 978-94-6284-138-3