Contributions of executive control to individual differences in word production

ISBN: 9789076203492

Printed and bound by Ipskamp Drukkers, Nijmegen
Cover design by Zeshu Shao

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Een wetenschappelijke proeve
op het gebied van de Sociale Wetenschappen

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. Mr. S.C.J.J. Kortmann,
volgens besluit van het college van decanen
in het openbaar te verdedigen
op dinsdag 20 augustus 2013 om 10.30 uur precies

door

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The research reported in this thesis was supported by a grant from the Max-Planck-Gesellschaft zur Förderung der Wissenschaften, München, Germany.

Contents

Chapter 1: Introduction

Speaking is a unique ability of human beings. However, there are striking individual differences in speaking. For example, different speakers often use different words and sentences to describe the same scene, and they differ in the habitual speech rates and the fluency. The sources of these individual differences are still largely unknown. It seems that individual differences arise because people differ in their knowledge of the language (i.e. in the size of their vocabulary and their knowledge of grammar) and in the way they apply this knowledge. In this thesis, I explored contributions of executive control processes to the individual differences in the efficiency of single word production.

In the next section I briefly discuss current models of single word production and then describe some of the evidence for the involvement of executive control processes in lexical access and outline the executive control theory of Miyake et al. (2000), which guided the initial part of the research. Finally, I provide an overview of the content in the following chapters.

Current models of lexical access

How to select one word during speaking (i.e. lexical access) is one of the most discussed topics in psycholinguistics. Considerable research effort has been directed at studying lexical access, and thereby influential theories and computational models have been proposed (e.g., Caramazza, 1997; Dell, 1986; Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000; Roelofs, 1992). In general, theories and models agree that lexical access involves two steps: the selection of a word unit (sometimes called the lemma) from the mental lexicon and the encoding of the associated word form. The distinction between these two stages is supported by numerous empirical findings from chronometric experiments (e.g., Schriefers, Meyer, & Levelt, 1990), computational modeling (e.g., Dell, 1986; Foygel & Dell, 2000), analyses of speech errors in healthy speakers and brain-damaged patients (e.g., Badecker, Miozzo, & Zanuttini, 1995; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Goodglass, Kaplan, Weintraub, & Ackerman, 1976; Kay & Ellis, 1987), and brain imaging studies (e.g., Indefrey & Levelt, 2004; de Zubicaray, Wilson, McMahon, & Muthiah, 2001). Some theories claim that information is retrieved in distinct, non-overlapping steps (e.g., Indefrey & Levelt, 2004; Levelt et al., 1999). However, there is now mounting evidence that information cascades through the system, which implies that the retrieval of a word form can be initiated before a unique lemma has been selected (Morsella & Miozzo, 2002; Meyer & Damian, 2007; Roelofs, 2008d; see also Dell, 1986). Moreover, there appears to be feedback from the morpho-phonological to the lemma level of processing (e.g., Gordon & Dell, 2001; Jaeger, Furth, & Hilliard, 2012; Rapp & Goldrick, 2000; but see Roelofs, 2004).

Models of lexical access generally agree that the encoding of word forms comprises morphological encoding processes, where one or more morphemes are selected and combined, and phonological encoding processes, where the word's segments are selected and syllabified. The output of these processes is a phonological representation that is further specified during phonetic encoding processes. The resulting phonetic representation constitutes the input to the articulatory planning processes (e.g., Levelt et al., 1999). During lexical access speakers monitor their speech planning, probably referring primarily to the phonological representation (e.g., Levelt et al., 1999; Roelofs, 2004).

For the present purposes, only the first step of lexical access, lexical selection, is relevant. A common view in the literature is that lexical selection is a competitive process. Different lemmas may become simultaneously activated and compete for selection. This implies, among other things, that the ease of selecting a given lemma depends on the number and activation levels of the co-activated competitors (e.g., Abdel Rahman & Melinger, 2009; Bloem & La Heij, 2003; Howard, Nickels, Coltheard, & Cole-Virtue, 2006; Levelt et al., 1999; Roelofs, 1992; Starreveld & La Heij, 1996). By contrast, other models proposed that lexical selection is not a competitive process, and that the target word is selected as soon as a threshold of activation is reached (e.g., Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). I return to the mechanisms of lexical selection in Chapter 6.

Involvement of executive control in single word production

It is reasonable to assume that both domain-general abilities and language-specific abilities contribute to individual differences in lexical access. However, in this thesis, I concentrated on the domain-general aspect, specifically executive control. Intuitively speaking is effortless and simple. However, it is not as easy as it seems. To speak efficiently, general cognitive mechanisms must be involved to support the language system, although the extent of their involvement may vary and depend on the specific situation. In single word production, we need the conceptual system and sometimes perceptual systems to select a concept to be verbalized; we need the memory system to retrieve word knowledge, and muscles to execute articulatory gestures. Most importantly we need a top-down control system, for instance to direct our visual attention to the object to be named, to select lexical items appropriate for the communicative situation (e.g., uttered in the target language and using the correct register), and we need to monitor and sometimes correct the speech output. This top-down control system is likely to be the general executive control system, which also controls other types of actions (cf. Roelofs, 2003).

Empirical evidence for the involvement of executive control during word production comes from a variety of sources (see Roelofs, 2008b for a review). For instance, studies of bilingualism have shown that fluent bilingual speakers perform better in a letter fluency task than monolingual speakers, presumably due to enhanced executive control ability (e.g., Luo, Luk, & Bialystok, 2010; Festman, Rodriguez-Fornells, & Münte, 2010). Moreover, brain-damaged patients with deficient inhibition ability had difficult to produce words under high lexical competition than the normal controls (e.g., Thompson-Schill et al., 1998; Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005). In addition, age-related decline in spoken word recognition and production has sometimes been linked to declines in executive control (e.g., Taler, Aaron, Steinmetz, & Pisoni, 2010).

The executive control system regulates self-perception, thoughts, and goal-directed actions. There are several somewhat different ways of conceptualizing and decomposing executive control processes (e.g., Baddeley, 1986; Miller & Cohen, 2001; Norman & Shallice, 1986; Posner & Petersen, 1990). Here, I follow one of the most influencial theories of executive control (Miyake et al., 2000), who distinguish three components of executive control: (i) shifting of tasks or mental sets, (ii) monitoring and updating of working memory representations, (iii) inhibition of dominant responses. This theory of executive control was originally developed to explain individual performance differences in complex tasks such as the Wisconsin Card Sorting Test or the Tower of Hanoi puzzle. However, the framework may also explain individual differences in linguistic tasks, like picture naming.

In particular, the *shifting* ability may be important for bilingual speakers to help them select the target language and switch between languages, but it is not obvious how it would be involved in monolingual picture naming. In contrast, the *updating* ability seems important for lexical access. For example, in picture naming task, participants need to maintain the task, i.e. using their native language or a second language, referring to the event shown in a picture or the agent, and so. Finally, the *inhibition* ability may also be important during word production and other language processing tasks. It involves suppression of the activation of incorrect responses or competitors of target words. As discussed throughout this thesis, inhibition may play a crucial role during lexical selection.

Overview of the thesis

The main goal of this thesis is to investigate the contribution of executive control during word production in healthy adults. The thesis explored how word production processes are influenced by updating, shifting and inhibition from the individual differences perspective. Word production ability was assessed in picture naming paradigm. I measured error rates, response latencies, and, in one study, event-related brain potentials. Components of executive control were assessed by individual measures which were explained in following chapters.

Chapter 2 studied the contributions of the three components of executive control to object and action naming. The findings showed the impact of updating and inhibition on picture naming. Furthermore, Chapters 3 and 4 focused on effect of two subcomponents of inhibition on object naming, namely selective and nonselective inhibition. Chapter 5 presents the norms of action pictures in Dutch, which was used for stimuli selection in Chapter 6. Chapter 6 reported an EEG study focusing on the neural mechanism of inhibition during object and action naming. Finally, Chapter 7 summarized findings of this thesis and discussed possible implications.

Chapter 2: Sources of Individual Differences in the Speed of Naming Objects and Actions: The Contribution of Executive Control

This chapter appeared as: Shao, Z., Roelofs, A., & Meyer, A. S. (2012). Sources of individual differences in the speed of naming objects and actions: The contribution of executive control. *Quarterly Journal of Experimental Psychology*, *65*, 1927-1944.

CHAPTER 2: INDIVIDUAL DIFFERENCES IN NAMING SPEED

Abstract

We examined the contribution of executive control to individual differences in response time (RT) for naming objects and actions. Following Miyake et al. (2000), executive control was assumed to include updating, shifting, and inhibiting abilities, which were assessed using operation-span, task switching, and stop-signal tasks, respectively. Experiment 1 showed that updating ability was significantly correlated with the mean RT of action naming, but not of object naming. This finding was replicated in Experiment 2 using a larger stimulus set. Inhibiting ability was significantly correlated with the mean RT of both action and object naming, whereas shifting ability was not correlated with the mean naming RTs. Ex-Gaussian analyses of the RT distributions revealed that updating ability was correlated with the distribution tail of both action and object naming, whereas inhibiting ability was correlated with the leading edge of the distribution for action naming and the tail for object naming. Shifting ability provided no independent contribution. These results indicate that the executive control abilities of updating and inhibiting contribute to the speed of naming objects and actions, although there are differences in the way and extent these abilities are involved.

CHAPTER 2: INDIVIDUAL DIFFERENCES IN NAMING SPEED

Introduction

A key component of the language production system is lexical access, the retrieval of words from the mental lexicon. Without lexical access speaking is not possible. It is therefore not surprising that considerable research effort has been directed at understanding this process. This work has led to the development of a number of detailed models of lexical access (e.g., Caramazza, 1997; Dell, 1986; Levelt, Roelofs, & Meyer, 1999). Though the models differ in important ways, there is general consensus that the processes involved in producing a single word can be roughly parsed into pre-linguistic processes leading to the selection of a concept to be expressed, lexical retrieval processes leading to the retrieval of the syntactic and morpho-phonological properties of the word, and post-lexical articulatory planning and self-monitoring processes (e.g., Bock, 1982; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt, 1989; Levelt et al., 1999; Rapp & Goldrick, 2000).

Speakers rarely emit random words at random times but instead typically use language in order to attain certain goals, be it to communicate to others or to structure their own thoughts. Therefore, lexical access, like any other goal-directed activity, must be governed by executive control processes (e.g., Roelofs, 2003). These are general cognitive processes that define and maintain the individual’s goals, recruit appropriate perceptual and response mechanisms, and monitor their performance (e.g., Norman & Shallice, 1986; Posner & Petersen, 1990). When we speak, we need to choose our words wisely (e.g., considering our goals and the common ground between interlocutors; Nilsen & Graham, 2009; Ye & Zhou, 2009), allocate sufficient processing capacity to our speech planning processes (e.g., Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a, 2008b), and monitor our speech output for appropriateness and correctness. We also need to choose and maintain an appropriate speech rate and register (e.g., child-directed speech or the formal style required for a sermon, see Meyer, Konopka, Wheeldon, & van der Meulen, 2012). All of this requires the involvement of executive control. This holds even when speakers produce single words in response to line drawings, as is often the case in experimental studies of lexical access. Here the speakers must consistently attend to the stimuli, remember the precise instructions concerning the content of the utterances (e.g., to name the objects, or their colour, or the action shown in the picture), the linguistic form (e.g., to produce bare nouns or determiner noun phrases, in their first or second language) and any specific instructions concerning the speed or accuracy of the responses (e.g., to be quick but also accurate, to initiate or complete the response within a specific time interval or to articulate very carefully), and monitor their performance. An important topic in current language production research is how the core processes of lexical access, captured in the models mentioned above, and executive control processes jointly determine performance in linguistic tasks (e.g., Roelofs, 2008b; Roelofs & Piai, 2011). For example, in the WEAVER++ model of spoken word production (Levelt et al., 1999; Roelofs, 2003, 2008c), information about words is stored in a large associative network, which is accessed by spreading activation. Executive control is achieved by condition-action rules that determine what is done with the activated lexical information depending on the goal and task demands in working memory.

Much of the work on executive control in language production has taken a classic experimental approach, for instance examining the effect of different types of distractors on picture naming (e.g., Roelofs, 2008b, for a review). However, Bower (1975) has pointed out that theories about the involvement of specific processing components in cognitive tasks should not only be tested experimentally, but also by examining the predictions they make about individual differences. If a cognitive component A plays a non-trivial role in determining the performance in task B, individuals differing in the ability underlying A should differ in their performance in task B. Thus, if executive control plays a substantial role in efficient lexical access, then people differing in executive control abilities should differ in their performance in typical lexical access tasks, such as object or action naming. By contrast, if the involvement of executive control in lexical access is trivial (i.e., if all healthy speakers can easily maintain the required level of executive control throughout an experiment) no correlation should be seen. These hypotheses were tested in the studies reported in the present article: We asked participants to name sets of objects and actions, assessed their executive control ability and determined whether there was a relationship between their performance in the naming tasks and the indicators of executive control ability.

Several strands of research have linked executive control ability to differences in word production and other language tasks. For instance, evidence suggests that deficits in executive control contribute to the impaired language performance of individuals with specific language impairment (SLI), which is a disorder of the acquisition and use of language in children who otherwise appear to be normally developing and which may persist into adulthood (e.g., Im-Bolter, Johnson, & Pascual-Leone, 2006; Montgomery, Magimairaj, & Finney, 2010). The deficits include working memory capacity and inhibiting ability. Moreover, evidence suggests that brain-damaged patients with deficient inhibiting abilities have difficulty producing words under conditions of high lexical competition in a word generation task (e.g., Thompson-Schill, Swick, Farah, D'Esposito, Kan, & Knight, 1998; Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005). Studies of ADHD have indicated that deficient inhibiting abilities caused disfluencies during sentence production (e.g., Engelhardt, Corley, Nigg, & Ferreira, 2010). In the aging literature, age-related declining inhibiting abilities have been associated with increased lexical competition effects in both spoken word recognition and production (e.g., Taler, Aaron, Steinmetz, & Pisoni, 2010). Finally, in studies of bilingualism, fluent bilinguals performed better in a letter fluency task than monolinguals, which was attributed to enhanced executive control abilities in bilinguals compared with monolinguals (e.g., Luo, Luk, & Bialystok, 2010; Festman, Rodriguez-Fornells, & Münte, 2010). Based on these findings, one might expect that variations in executive control ability within a group of healthy adults could also be related to differences in speech production. Executive control processes have been conceptualised in slightly different ways (e.g., Baddeley, 1986; Miller & Cohen, 2001; Norman & Shallice, 1986; Posner & Petersen, 1990). In general, executive control refers to the regulatory processes that ensure our perceptions, thoughts, and actions are in accordance with our goals. It is often assumed that executive control consists of several component processes. An influential decomposition of executive control has been proposed by Miyake and colleagues (e.g., Friedman, Miyake, Corley, Young, Defries, & Hewitt, 2006; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). They distinguish three types of executive control abilities: (i) monitoring and updating of working memory representations, henceforth “updating”, (ii) inhibiting of dominant responses, henceforth “inhibiting”, and (iii) shifting of tasks or mental sets, henceforth “shifting”.

Though the framework of Miyake and colleagues was developed to account for individual differences in performing complex tasks such as the Wisconsin Card Sorting Test or the Tower of Hanoi puzzle, it can be applied to the task of picture naming. As pointed out above, in naming tasks, participants must keep the instructions concerning task demands (to be fast, to be accurate, to use only nouns, etc.) in mind while engaged in the naming task itself and they should consistently evaluate their performance with respect to the goals implied by the instructions. Given that some of the processes involved in naming require processing capacity, participants need to distribute their resources between these executive control processes and the naming processes. Inhibition of responses might be involved during self-monitoring processes, when incorrect responses (for instance a semantic associate to the target name) come to mind and need to be suppressed. It is less obvious how task switching might be relevant when participants carry out the same task on all trials. However, it might be involved whenever participants switch from one picture to the next, and therefore have to prepare a new response rather than repeating the previous one, or when they switch from planning a response to monitoring their output.

In the present article, we report two studies that examined whether indicators of executive control ability correlated with performance speed in picture naming tasks. In both studies, the participants named two sets of pictures, showing objects and actions, respectively. Executive control processes should be engaged in both action and object naming, but they might play a more prominent role in action naming. Action naming can be considered to be more demanding than object naming, not only because verbs are semantically and grammatically more complex than nouns (e.g., Clark & Gerrig, 1983; Gentner, 1982; Saffran, Schwartz, & Marin, 1980), but also because the visual and conceptual processes preceding lexical selection are likely to be more complex (e.g., Szekely et al., 2005). In order to find an appropriate verb the speakers must often identify (but not name) the agent and objects in the picture and the relationship between them, or they must attend to subtle visual cues (e.g., speed lines representing movement). Thus, action naming might be more taxing than object naming, and therefore a correlation of naming speed and indicators of executive control ability might be more readily seen for actions than for objects.

In the first experiment, we only assessed the participants' updating ability, which seems most obviously relevant in the naming task. This ability is typically assessed in complex span tasks (e.g., reading span, operation span), which require participants to store and regularly update memory representation while carrying out another complex cognitive task. There are various types of complex span tasks, differing in the combinations of tasks, timing and instructions (for a review see Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). We opted for the operation span task, which requires participants to solve simple mathematical problems while memorizing word lists of varying length. Performance on this task has been shown to correlate well with performance in complex cognitive tasks such as reading comprehension and tests of fluid intelligence (e.g., Unsworth & Engle, 2005, 2006). Miyake et al. (2000) provided evidence that the operation-span task assesses the updating ability but not the shifting and inhibiting abilities. The question we addressed here was whether operation-span scores would also be correlated with performance in simple naming tasks. In the second experiment, we additionally assessed the participants' inhibiting and shifting abilities using stop-signal and shape-colour switching tasks, respectively. Details about these latter tasks will be given below. In both studies, we expected that picture naming speed would correlate with measures of executive control and that the correlation would be stronger for action naming than for object naming.

Experiment 1

In Experiment 1, the participants first named sets of object and action pictures, and then their updating ability was measured using the operation-span task. The goal was to investigate whether the participants' average speed in the object and action naming task correlated with their score on the operation-span test.

Method

Participants. The participants were 28 undergraduate students (4 men, M_{age} = 19.1 years, age range: 18 to 22 years) of the University of Birmingham (UK), who participated in the experiment in exchange for course credits. All participants were native English speakers and had normal or corrected-to-normal vision.

Speeded Naming Tasks. ***Materials.*** For the speeded object naming tasks, 52 black-and-white line-drawings were selected from the Snodgrass and Vanderwart (1980) corpus. For the speeded action naming task, 61 line-drawings of actions were selected from the corpus provided by Druks and Masterson (2000). Items were selected to cover a broad range of name frequencies. Object and action picture names were matched for word frequency, using the CELEX data base (mean word form frequencies/million: M_{object} = 7.09, SD= 7.24, M_{action}= 9.28, SD= 20.38, $F(1, 111) = .54$, $p = .47$). The picture names are listed in Appendix A. All pictures were scaled to fit into frames of 2.65 by 2.65 cm on the participant's screen (1.51° of visual angle).

Procedure. On each trial, a fixation cross (+) was presented first for 800 ms in the centre of the screen, followed by a picture, which was shown for 600 ms. Then a red flashing exclamation mark was presented for maximally 1400 ms to remind the participants to speed up. The inter-stimulus interval was 1500 ms. A trial ended as soon as the voice key was triggered by the participant's verbal response. If the participant did not respond within 2000 ms from the onset of the stimulus picture, the trial was terminated automatically. In the instructions the participants were encouraged to name the pictures before they disappeared from view.

The object and action pictures were shown in separate test blocks. All participants carried out the object naming task first. Each test block began with four practice trials. The order of the experimental items was random and different for each participant. The participants were tested individually.

Operation Span Task. The operation span task, adapted from Turner and Engle (1989), is thought to assess working memory capacity, which specifically reflects the updating ability (Miyake et al., 2000). Participants are required to evaluate the correctness of simple mathematical operations while remembering unrelated words for later serial recall.

Materials. For the task, 60 math operations and English words were used. The operations and words were taken from Tokowicz, Michael, and Kroll (2004; Turner & Engle, 1989).

Procedure. The same procedure was used as in Turner and Engle (1989). On each trial, a fixation cross was presented for 800 ms. After a blank interval of 100 ms a mathematical operation and a word were presented simultaneously in the centre of the screen (e.g., (18/3) – 4 = 2? Hotel). The participants were required to read the operation and the word aloud and then press one of two keys (i.e. "C" key and "M" key) on their keyboard to indicate whether or not the operation was correct. After a number of trials, varying randomly between 2 and 6, a recall cue (RECALL) was presented and participants had to write down the words seen since the beginning of the experiment or since the last recall test. The task was self-paced and took on average 15 minutes. This task was administered after the naming tasks.

Analysis. The operation-span score was calculated as the sum of words that were recalled in the proper order on trials with correct responses to the mathematical problem. A participant's score could range from 0 to 60.

Apparatus. The stimuli were presented on a Samsung SyncMaster 753s monitor. A SHURE SM86 and a Cedrus SV-1 voicekey were used to record the participants' spoken responses and a Microsoft keyboard to record their manual responses in the operation-span test. The tests were controlled by E-Prime 2 software.

Results

The data from four participants were excluded from further analyses because the number of correct math responses in the operation-span task was lower than the minimum acceptable rate (85%) suggested by Turner and Engle (1989). This rate was used to avoid trading off between solving math operations and memorizing words. The average score for the remaining participants was 36.14 (*SD* = 7.08), which is higher than the ranges reported in other studies but well below ceiling (e.g., Arnell, Stokes, & Maclean, 2010 [*Mean* = 35.57; *SD* = 9.68]; Unsworth & Engle, 2005 [*Mean* = 13.25; *SD* = 6.58]).

The remaining participants' responses in the naming tasks were coded for speed and accuracy. Nine items of the object naming task and seven items of the action naming task were excluded because the rate of correct responses was below 60%. The error rates and the mean naming RTs for correct responses to the remaining items are shown in Table 1. As expected, participants were faster to name object than action pictures. This difference was significant in analyses using participants (t_1) and items (t_2) as random variables, t_1 (27) = 4.22, $p < .01$, t_2 (111) = 2.30, $p < .05$. Participants made slightly more errors in the object than in the action naming task, but this difference was not significant.

Table 1

Results of Experiment 1: Mean latency and error rate of object and action naming and mean operation-span score. Latencies are given in milliseconds. SD = Standard deviation

	Mean	SD	Error rate (%)
Object naming	794	69	15.00
Action naming	844	90	13.00
Operation span	36.14	7.08	

The participants' mean RTs in the naming tasks were correlated with each other and with the scores in the operation-span task. There was a significant positive correlation between the mean RTs in the object and action naming tasks, $r = .74$, $p < .01$. This indicates that participants who were fast, or slow, to name the objects tended also to be fast, or slow, to name the actions. Most importantly, the mean naming RTs correlated negatively with the operation-span scores, indicating that the higher the operation-span scores (i.e., the greater the updating ability), the faster the pictures were named. However, only the correlation of the operation-span scores with the action naming RTs, but not the correlation with the object naming RTs, was statistically significant, $r = -.42$, $p < .05$, $r = -.27$, $p = .17$, respectively.

Experiment 2

The results of Experiment 1 suggest that the participants' naming speed was constrained by their updating ability. The first goal of Experiment 2 was to replicate the correlation between naming speed and the operation-span scores seen in Experiment 1 with a new sample of participants and larger sets of stimuli. As indicated, evidence suggests that the operation-span scores reflect the speakers' updating ability, but not their shifting or inhibiting abilities (Miyake et al., 2000). The second goal of Experiment 2 was to examine the involvement of these latter aspects of executive control in the naming task as well. To do so, we used the stop-signal and shape-colour switching task described below.

Moreover, we examined not only the correlations of measures of executive control with the participants' mean RTs in the naming tasks, but also with parameters characterising their RT distributions. We did not perform these analyses for Experiment 1 because the number of trials was too small. In order to characterize each participant's RT distribution, we performed ex-Gaussian analyses. The ex-Gaussian function consists of a convolution of a Gaussian (i.e., normal) and an exponential distribution and generally provides good fits to empirical RT distributions (e.g., Luce, 1986; Ratcliff, 1979). The analyses provide three parameters characterizing a distribution, called μ, σ, and τ. The parameters μ and σ reflect the mean and standard deviation of the Gaussian portion respectively, and τ reflects the mean and standard deviation of the exponential portion. The mean of the whole distribution equals the sum of μ and τ. Thus, ex-Gaussian analyses decompose mean RTs into two additive components, which characterize the leading edge (μ) and the tail (τ) of the underlying RT distribution. In examining individual differences in the magnitude of the three ex-Gaussian parameters, Schmiedek, Oberauer, Wilhelm, and Wittmann (2007) identified latent factors for each of the three ex-Gaussian parameters using structural equation modeling for a battery of choice reaction tasks. These factors had differential relations to the criterion constructs of working memory capacity and fluid intelligence. Individual differences in τ, but not in μ and σ, predicted individual differences in working memory capacity and fluid intelligence. Tse, Balota, Yap, Duchek, and McCabe (2010) also observed that the τ parameter in three attention tasks was uniquely related to working memory measures.

In the present experiment, we correlated each participant's scores for each of the three executive control tasks with the three parameters obtained for the distribution of their action and object naming RTs. Based on the results obtained in the earlier studies, we expected the executive control ability of updating to correlate with τ rather than μ. We had no expectations concerning the relationship between the ex-Gaussian parameters and the inhibiting and shifting abilities.

Method

Participants. The participants were 24 undergraduate students (10 men, *Mean age* = 21.63 years, range: 18 to 38 years) of the University of Birmingham. They received £ 9.00 for their participation. All participants were native English speakers and had normal or corrected-to-normal vision and normal hearing. None of the participants had participated in Experiment 1.

Speeded Naming Tasks. ***Materials and procedure.*** The same tasks, object and action naming, were used as in Experiment 1. However, we used larger sets of stimuli, namely 162 line-drawings of objects and 100 line-drawings of actions adapted from Druks and Masterson (2000). The picture names are listed in Appendix A. The object and action pictures were matched for visual complexity, imageability, familiarity, age-of-acquisition, and word frequency, using norms provided by Druks and Masterson (see Appendix B). Word frequencies were obtained from the Francis and Kucera (1982) count. The other values were derived by rating studies, using 7 point-scales. Visual complexity refers to the visual complexity of the drawings. Imageability indicates how easily participants could form a mental image of the object or action event when given its name. Familiarity indicates how familiar the object or action names were. Finally, age-of-acquisition indicates the subjective estimate of the age (in years) at which the names was learned. As in Experiment 1, the participants first named the object pictures and then, after a short break, the action pictures.

Ex-Gaussian analyses. The ex-Gaussian parameters μ, σ, and τ were estimated from the naming RT data using the quantile maximum likelihood estimation method proposed by Brown and Heathcote (2003). The parameters were estimated separately for object and action naming and for each participant individually using the QMPE software with ten quantiles (Brown & Heathcote, 2003).

Operation-Span Task. The task was administered in the same way as in Experiment 1. The results of the operation-span task were analyzed as in the preceding experiment.

Stop-Signal Task. ***Materials and procedure.*** The Stop-Signal Task assesses the ability to inhibit a response. In selecting the stimuli and designing the trials we followed Verbruggen, Logan, and Stevens (2008). There were visual and auditory stimuli. The visual stimuli were a fixation cross, a square (1.5 by 1.5 cm) and a circle (1.5 cm in diameter), and the auditory stimulus was a 750 Hz tone with a duration of 75 ms.

The task consisted of a practice block of 32 trials and three experimental blocks of 64 trials each. Each block consisted of 75% go trials and 25% stop trials, presented in random order. On a go trial, a fixation cross (+) was presented in the middle of the screen for 250 ms, followed immediately by a square or a circle, shown in the same location. Squares and circles appeared equally often, in a random order. The participants were instructed to press the "/" key on the keyboard when they saw a circle and the "Z" key when they saw a square. The stimuli remained on the screen until the participant responded for a maximum of 1250 ms.

The stop trials had the same structure except that the tone was played shortly after the offset of the fixation cross. Participants were instructed to withhold their response on stop trials. The time interval between the offset of the fixation cross and the onset of the tone (the stop signal delay) was initially set to 250 ms. When the participant successfully inhibited the response on a given stop trial, the delay in the following stop trial was increased by 50 ms, making the task slightly harder; when the participant failed to inhibit the response on a given stop trial, the delay was decreased by 50 ms, making the task slightly easier.

Apparatus. The same equipment was used as in the preceding experiment. The tone was presented using Beyerdynamic DTX 700 Trendline headphones.

Analysis. Following Verbruggen et al. (2008), each participant's stop-signal RT (SSRT) was estimated by subtracting the mean stop-signal delay across all trials from the mean RT on go trials. Short SSRTs indicate that participants can stop their responses relatively late during response preparation and are indicative of good inhibitory control.

Shape-Color Switching Task. ***Materials and procedure.*** This task is thought to assess shifting ability, which means the ability to shift between two tasks or mental units (Meiran, 1996; Miyake, Emerson, Padilla, & Ahn, 2004). The stimuli were four colored geometric figures: a red and a green square (1.3 by 1.3 cm), and a red and a green circle (1.3 cm in diameter). On each trial, one figure was presented, and depending on its position on the screen, the participants had to categorize it either with respect to its color (pressing the "↓" button for red, and the "↑" button for green), or with respect to its shape (pressing the "↓" button for circle, and the "↑" button for square). There were six blocks (i.e., two color blocks, two shape blocks and two mixed blocks). Each color and shape blocks included 48 trials, and each mixed blocks included 128 trials. In the color blocks, all stimuli were presented in the top two quadrants of the screen and the participants were required to categorize them with respect to their color. In the shape blocks, the stimuli were presented only in the bottom two quadrants of the computer screen and participants were required to categorize them with respect to their shape. The color and shape blocks served as practice blocks. In the critical mixed blocks, the stimuli were presented in clockwise rotation around all four quadrants. Participants were required to respond to the color when the stimuli were presented in either of the top two quadrants and to respond to the shape when they were presented in either of the bottom two quadrants. The stimulus disappeared as soon as the participant pressed a response button. The response-stimulus interval was 150 ms. The shifting RT was the difference between the mean RT in the third block that required a mental shift (trials from the lower right and upper left quadrants) and the mean RT of the third block in which no shift was necessary.

Results and Discussion

The results obtained from four participants were excluded from all analyses because of poor performance in the operation-span task (two participants with less than 85% correct responses) or in the stop-signal task (two participants with 35% and 61% correct responses). Nine object pictures and five action pictures were excluded from the analyses because the rate of correct responses was less than 60 %. The mean naming RTs and error rates for the remaining items are shown in Table 2. As in Experiment 1, the naming RT were significantly shorter for object than for action pictures, $t_1(19) = 7.11, p < .01$, $t_2(260) = 11.22, p < .001$. The error rates did not differ. On the stop-signal task, the accuracy rate of no-signal go trials was 91%, and the estimated mean RT on no-signal go trials was 645 ms. Table 2 lists the mean operation-span scores, stop-signal RTs, and shape-color shifting latencies.

Table 2
Results of Experiment 2: Mean latency and error rate of object and action naming, mean operation-span score, mean stop-signal latency, and mean shape-color shifting latency. Latencies are given in milliseconds. SD = Standard deviation

	Mean	SD	Error rate (%)
Object naming	705	69	11.00
Action naming	782	70	11.00
Operation span	43.20	9.15	
Stop signal	279	50	5.00
Shape-color	394	187	7.00

The correlations among naming RTs and executive control indices are shown in Table 3. We found that the mean RTs for action and object naming were highly correlated. Both correlated negatively with the scores in the operation-span task, though only the correlation between the action naming RT and the operation-span score was significant. This pattern closely replicates the findings of Experiment 1, and indicates the involvement of the updating ability in picture naming.

Table 3
Results of Experiment 2: Correlations among mean object and action naming latencies and scores for the executive control tasks.

	Object	Action	Operation span	Stop signal
Action	.76**			
Operation span	-.38	-.54*		
Stop signal	.45*	.45*	-.09	
Shape-color	.36	.36	-.10	.45*

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

We estimated the parameters μ, σ, and τ for the object and action naming RT distributions for each participant and computed the correlations of these parameters with the participants' operation-span scores. We found a significant negative correlation between the operation-span score and τ for both object and action naming, $r = -.45$, $p < .05$, $r = -.62$, $p < .01$, respectively. There were no correlations between operation-span score and the parameters μ and σ. The negative correlation between operation-span score and τ is in line with the evidence obtained by Schmiedek et al. (2007) and Tse et al. (2010) that τ, as opposed to μ and σ, is uniquely related to working memory measures.

The stop-signal RT was significantly correlated with the mean RTs for object and action naming. This indicates the involvement of inhibitory control in both object and action naming. Moreover, the ex-Gaussian analyses showed a positive correlation of the stop-signal RT with τ for object naming, $r = .71$, $p < .01$, and a positive correlation with μ for action naming, $r = .58$, $p < .05$. Thus, the inhibiting ability is reflected in the leading edge of the RT distribution of action naming. Individual differences in the leading edge concern shifts of the whole RT distribution. In contrast, the inhibiting ability is reflected in the tail of the RT distribution of object naming. Individual differences in the tail concern differences that are present on the very slow trials only. This suggests that the inhibiting ability is engaged on most of the trials in action naming, but only on the occasional very slow trial in object naming.

The participants' average shifting latencies in the shape-color task did not correlate significantly with their mean object or action naming RTs, suggesting that differences in shifting ability, as measured in this task, do not contribute much to differences in mean naming latencies. However, the ex-Gaussian analyses showed a positive correlation of shifting latency with τ for object naming, $r = .54$, $p < .05$, and a marginally significant positive correlation of shifting latency with μ for action naming, $r = .41$, $p = .07$. As with the inhibiting ability, this suggests that the shifting ability is engaged on most of the trials in action naming, but only on the occasional very slow trial in object naming.

Finally, Table 3 indicates that the operation-span scores were not correlated with the stop-signal and shifting latencies. However, stop-signal and shifting latencies were positively correlated. Therefore, we computed partial correlations between ex-Gaussian parameters of the naming RTs and the stop-signal RT controlling for shifting latency. This analysis showed that stop-signal RT was still positively correlated with τ for object naming, $r = .61$, $p < .01$, and with μ for action naming, $r = .43$, $p < .05$. Upon controlling for stop-signal RT, the shifting latency correlated only marginally with τ for object naming, $r = .36$, $p = .06$, but not with μ for action naming, $r = .23$, $p = .17$. These results indicate that shifting ability did not provide a significant independent contribution to the naming RTs.

A rather unique feature of our studies was that participants were instructed to respond if possible before the stimuli disappeared from the screen at 600 ms and that a flashing light reminded them of this on every trial. This may not only have encouraged the participants to respond fast, but it could also have affected the parameters of the RT distributions. This in turn would imply that our results might not generalize to other studies. To assess the effects of the response deadline on the parameters of the RT distributions, we ran a follow-up experiment with 20 participants who named the same pictures as in Experiment 2 either under the same stringent timing conditions, or under more relaxed conditions, where they were simply asked to name the picture fast and accurately. For practical reasons the experiment was conducted in Dutch. The order of testing object and action pictures and of using the two speed instructions was counterbalanced across participants. We compared the parameters from the ex-Gaussian analyses across speed instructions. For object naming, we found no difference in μ ($t(19) = 1.66$, $p = .11$) or τ ($t(19) = .25$, $p = .80$). Thus, the speed instructions did not affect the leading end or the tail of the distribution. For the action naming task, we found a difference in μ ($t(19) = 2.58$, $p = .02$), indicating that the participants were overall faster under speed instructions, but there was no difference in τ ($t(19) = 1.54$, $p = .14$), demonstrating that the proportion of slow responses was not affected by the speed instructions.

General Discussion

In two studies, we examined the contribution of executive control ability to individual differences in RTs for naming objects and actions. Following Miyake et al. (2000), executive control was assumed to include updating, shifting, and inhibiting abilities, which were assessed using operation-span, task switching, and stop-signal tasks, respectively. Our results indicate that the updating and inhibiting abilities are involved in object and action naming, but in different ways and to different extents. Below, we first discuss the results concerning the contributions of the updating, inhibiting, and shifting abilities to naming speed in our studies, and then turn to the consequences of the present findings for understanding language performance in other experimental paradigms and natural conversation.

Contribution of updating ability

Experiment 1 showed that object and action naming RTs were highly correlated, as one might expect given that the processes of identifying the pictures, selecting suitable concepts and retrieving the associated lexical information must be very similar for the two naming tasks. There was a significant correlation between the speakers' updating ability and their mean action naming RT, but the correlation between updating ability and mean object naming RT was weaker and not significant.

A similar pattern of results was seen in Experiment 2. Again, the participants' mean object and action naming RTs were highly correlated, both correlated with updating ability, though only the correlation of updating and action naming was significant. Since the item sets (and thus the numbers of trials) were larger than in Experiment 1, ex-Gaussian analyses could be used to characterize the distributions of object and action naming RTs for each participant. These analyses showed that the parameter τ, characterizing the tail end of the distributions, was correlated with updating ability. The correlation was significant for both action and object naming. There were no correlations between updating ability and the μ and σ parameters, which characterize the leading edge of the distributions.

These findings, along with those of a number of other recent studies (e.g., Roelofs, 2008c, in press), highlight the usefulness of ex-Gaussian analyses in examining the role of executive control in naming performance. Whereas the analyses of the participants' mean RTs suggested that updating ability affected action naming only, the analyses of the entire distributions revealed that updating ability affected performance in both object and action naming.

In addition, the analyses offer some suggestions concerning the way updating ability might affect naming. The correlation with parameter τ indicates that updating ability is related to the proportion of slow responses in a speaker's RT distribution. Thus, the speakers with relatively poor updating ability did not uniformly name the pictures more slowly than speakers with better updating abilities (which would lead to a correlation of updating ability with μ), but they were more likely to respond very slowly on some of the trials. Unsworth, Redick, Lakey, and Young (2010) observed that in a sustained attention task τ, reflecting the proportion of very slow responses, was related to measures of working memory capacity and executive control (cf.

Schmiedek et al., 2007; Tse et al., 2010). The authors concluded that the slow responses reflected lapses in sustained attention (i.e., temporary loss of the task goal from working memory or brief moments of disengagement). When information about the task demands is temporarily lost from working memory, the information needs to be re-accessed and working memory must be updated during a trial, which will lead to a very slow naming response. In a naming task, updating ability may determine how well speakers keep the specific task demands, for instance to name the objects or the actions and to respond very quickly, in working memory. This would explain the correlation we observed between the τ of object and action naming and updating ability: Participants with good updating ability were consistently aware of the type of response required and, more importantly perhaps, the need to respond very fast.

The correlation of τ with updating ability is in line with research by Schmiedek et al. (2007) and Tse et al. (2010), who showed that τ was the strongest unique predictor of working memory capacity, which was linked to the updating ability by Miyake et al. (2000). Schmiedek et al. and Tse et al. used different ways of assessing updating ability and different tasks (e.g., involving manual responding). The convergence of results from studies using different tasks is important as it demonstrates the robustness of the relationship of updating ability and the incidence of slow responses in cognitive tasks.

Whereas Unsworth et al. (2010) argued for a relation between τ and lapses of attention, Schmiedek et al. (2007) hypothesized that the link between τ and working memory exists because the efficiency of information transmission in many tasks depends on how well arbitrary stimulus-response mappings are maintained. According to Schmiedek et al. (2007), many tasks involve arbitrary mappings between stimuli and responses. For example, in their own study, participants had to classify stimuli (e.g., words as plant or animal, digits as odd or even, arrows as upward or downward pointing) by pressing a left or right key. Bindings between stimulus and response representations in working memory (e.g., between the category animal and the left response key) are needed to mediate the selection of appropriate responses to stimuli, at least at the beginning of a new task. Even after moderate amounts of practice, when more durable associations between stimuli and responses are built in long-term memory, bindings in working memory may still contribute to efficient response selection. According to this hypothesis, the strength of temporary bindings determines the efficiency of information transmission between stimuli and responses, which is reflected in the τ parameter.

However, in the present studies, participants did not learn arbitrary bindings between stimuli and responses, but named pictures in their native language. Still, we obtained a correlation between τ and updating ability, which is related to working memory capacity (Miyake et al., 2000). Thus, the present findings are more compatible with the view of Unsworth et al. (2010) that τ is associated with temporary loss of the task goal from working memory or brief moments of disengagement than with the view of Schmiedek et al. (2007) that τ reflects how well arbitrary stimulus-response mappings are maintained in working memory.

Our interpretation of the data implies that long RTs occurred when the participants' executive control processes failed. An alternative is that long RTs arose when the lexical retrieval task is particularly taxing. One might speculate that, for whatever reason, participants with poor updating ability had smaller vocabularies than participants with better updating ability and that this difference in lexical knowledge mediated the observed correlation between τ and updating ability. This view predicts that slow responses should be particularly common for the more difficult lexical items. To assess this prediction, we identified the slowest 10% of the response times for each participant (i.e., 16 trials of object naming and 10 trials of the action naming task) and examined whether some items were more likely than other to occur in this slow response set. We found that 120 out of 162 object drawings and 74 out of 100 action drawings led to at least one slow response. No item occurred more than 11 times in the slow set: for object drawings, 7 items occurred 9 to 11 times, 56 items occurred once or twice, 57 items occurred 3 to 8 times; for action drawings, 1 item occurred 9 to 10 times, 34 items occurred 3 to 8 times and 39 items occurred once or twice. We also compared the name frequency and concept familiarity of the items leading to the slowest responses and those that never occurred in the slowest response set. No significant difference was found: for word frequency $t(160) = 1.74$, $p = .08$ for the object naming task, and $t(98) = 1.01$, $p = .29$ for the action naming task; and for concept familiarity, $t(160) = .91$, $p = .36$ for the object naming task, and $t(98) = 1.27$, $p = .21$ for the action naming task. Based on the post-hoc analysis, there is no clear evidence that slow responses were systematically associated with specific items.

In a follow-up experiment in Dutch described above, we asked speakers to name the same objects and actions as in Experiment 2 and we assessed their vocabulary using the Dutch version of the Peabody Picture Vocabulary Test (Dunn & Dunn, 2004). There was no significant correlation between the participants' τ parameters in the naming tasks and their vocabulary knowledge. This argues against the view that the correlations seen in Experiment 2 between the τ parameters and updating ability were mediated by differences in vocabulary.

Thus, we propose that updating ability may affect naming performance by determining how well a speaker stays ‘on task’. Further research is required to find out more about what it means 'to stay on task'. It is, for instance, possible that there are specific components in the naming process that rely particularly strongly on updating ability. For instance, it has often been proposed that conceptual planning processes and self-monitoring processes require processing capacity (e.g., Levelt, 1989; Oomen & Postma, 2002), whereas lexical access, though not an automatic process (e.g., Ferreira & Pashler, 2002; Cook & Meyer, 2008; Roelofs, 2008a), might be lower in capacity demands. Updating ability might specifically affect the efficiency of the conceptual processes, but not so much the lexical retrieval processes. In our materials, the action and object set were well matched for lexical characteristics, but action naming probably was more demanding in terms of the conceptualization processes. The finding that updating ability was correlated more strongly with the performance in the action than in the object naming task would fit in with the suggestion that updating ability affects the efficiency of conceptual processing. Updating might also affect the efficiency of specific types of monitoring processes. For instance, in the present studies speakers with good updating ability might be more likely than speakers with poorer updating ability to keep in mind the requirement to respond within 600 ms and to schedule their conceptual and linguistic planning processes and set their response criteria accordingly (see also Lupker, Brown, & Colombo, 1997; Meyer, Roelofs, & Levelt, 2003). This would have been more difficult for action than object naming, which would explain why updating ability appeared to have a somewhat stronger effect on action than object naming. Obviously further research is needed to determine exactly how and when updating ability affects the performance in naming tasks.

Contribution of inhibiting ability

In Experiment 2, we found that the object and action naming RTs also correlated significantly with inhibiting ability. Updating and inhibiting ability did not correlate with each other, in line with evidence of Miyake et al. (2000) that these two abilities constitute fairly independent component of executive control. When a picture is viewed, several response alternatives may become activated to different degrees (e.g., Levelt et al., 1999; Roelofs, 1992, 1997). For example, a picture of a cat may not only activate the response *cat*, but also responses like *feline*, *animal*, *tail*, *dog*, and so forth. Likewise, a picture of a man kicking a ball may not only activate the response *kick*, but also responses like *man*, *ball*, *foot*, *shoot*, *goal*, and so forth. Inhibiting ability may be engaged when these incorrect responses come to mind and have to be suppressed.

The ex-Gaussian analyses indicated that the inhibiting ability was reflected in the leading edge of the RT distribution of action naming, but in the tail of the RT distribution of object naming. This suggests that inhibiting ability was engaged on most of the trials in action naming, but only on the occasional very slow trial in object naming. Earlier, we indicated that action naming can be considered to be more demanding than object naming, not only because verbs are semantically and grammatically more complex than nouns, but also because the visual and conceptual processes preceding lexical selection are likely to be more complex. This might be the reason why the inhibiting ability was more regularly needed in action than object naming, which is reflected in the correlations between τ of action naming and μ of object naming. As for updating, more research is required to determine exactly how inhibiting ability is involved in naming. In a companion study (cf. Chapter 3) we observed that inhibiting ability predicted the participants' average RTs in a picture-word interference task, but not the size of the semantic interference effect (see also below). This demonstrates that inhibition, as measured by the stop-signal task, is nonselective, rather than being specifically involved in suppressing responses that are closely related to the target response.

Contribution of the shifting ability

Finally, differences in the third component of executive control, the shifting ability, were not related to differences in mean naming RTs. However, the ex-Gaussian analyses revealed a significant correlation between the shifting ability and the parameter τ of object naming, and a marginally significant correlation of shifting ability with the μ of action naming. However, after controlling for the contribution of the inhibiting ability, the correlation between shifting and the τ of object naming was only marginally significant and the correlation between shifting and the μ of action naming was no longer significant. These results suggest that the shifting ability does not contribute much to the speed of picture naming. Shifting may, however, be more important when words are spoken in context and when speakers need to rapidly disengage their attention from one concept and its name and turn to the next concept. It may also be important in dialogue, where speakers have to switch between primarily attending to their own speech planning and attending to the speech of the interlocutor.

Consequences for understanding language performance in other domains

We found that two of the three components of executive control identified by Miyake et al. (2000), namely updating and inhibiting, affected naming RTs, albeit in different ways and to different extents. Even though executive control abilities only accounted for part of the variance in the naming tasks, it might be useful to assess these abilities and estimate their effects on the target performance in other paradigms.

In psycholinguistics, picture naming is often not studied in isolation (as we did in the present studies), but researchers assess naming performance in task situations that more obviously engage executive control, such as Stroop-like paradigms. One of the workhorses in studying spoken word production is the picture-word interference paradigm. In this paradigm, speakers name pictures while trying to ignore superimposed written or spoken distractor words (e.g., Levelt et al., 1999). Naming RT is the main dependent measure. A central finding obtained with picture-word interference is that naming pictures takes longer when the distractor word belongs to the same semantic category as the picture name (e.g., pictured cat, categorically related word *dog*) than when the distractor is unrelated (e.g., pictured cat, word *pin*), an effect often referred to as "semantic interference". This finding has been taken as evidence that words compete for selection. The picture-word interference paradigm clearly not only taps into word production but also into executive control mechanisms. These mechanisms allow the participants to respond to the target picture rather than to the distractor word. For example, it seems likely that performance in picture-word interference experiments engages the inhibiting ability.

Individual differences in executive control abilities within and between picture-word interference experiments are typically not examined. However, given the present evidence that individual differences in executive control abilities contribute to naming RTs even in simple tasks, it is plausible to assume that these differences play even a larger role in picture-word interference performance. This may explain differences in results between studies. For example, a number of studies have reported distractor word effects in picture naming when participants simultaneously perform another unrelated task (e.g., Janssen, Schirm, Mahon, & Caramazza, 2008). However, several other studies could not replicate the semantic interference effect under divided attention (e.g., Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Piai, Roelofs, & Schriefers, 2011). Piai et al. (2011) argued that the difference in results between studies may be related to difference in executive control parameters between the participants groups, and they presented the results of computer simulations demonstrating the utility of this account. Taken together, the present findings and recent findings in the literature (e.g., Piai et al., 2011) suggest that the involvement of executive control in naming performance is not only of interest in its own right, but may also resolve discrepancies between studies.

Still, one might ask whether the influences discovered here – of updating and inhibiting – matter for actual speech production in everyday contexts. In other words, does a person’s executive control ability matter for communicative success? This issue needs to be assessed in further research. Our participants were young undergraduate students, whom one might expect to be rather homogeneous in executive control and linguistic abilities, as well as above average. In more heterogeneous samples the relationship between naming performance and executive control might be weaker or stronger. Legree, Pifer, and Grafton (1996) provided evidence that different executive abilities can be separated less clearly for homogeneous high-ability groups than for more heterogeneous lower-ability groups. The degree of speaker homogeneity may affect the correlation between measures of executive abilities and naming RTs. It remains to be seen whether individual differences in executive control ability have a non-trivial effect on the efficiency of lexical access in conversational settings. It is possible that staying ‘on task’ during lexical access is easier than in laboratory situations because of motivational reasons. Alternatively, staying on task might be more challenging because speakers need to divide their attention across different conceptual and linguistic planning tasks and because there are external distractions.

Conclusions

CHAPTER 2: INDIVIDUAL DIFFERENCES IN NAMING SPEED

We examined the contribution of executive control to individual differences in RT for naming objects and actions. Executive control was assumed to include updating, shifting, and inhibiting abilities, which were assessed using operation-span, task switching, and stop-signal tasks, respectively. Our results indicated that the updating and inhibiting abilities contribute to the speed of naming objects and actions, although there are differences in the way and extent that the abilities are involved. Future studies of picture naming should take the contribution of executive control to naming performance into account.

Appendix A

Target names of pictures in the object and action naming tasks

Category	Items
Object	Experiment 1 only: dentist, fan, ghost, globe, helmet, hoof, kite, lizard, log, magnet, microphone, mixer, needle, octopus, package, panda, parrot, peacock, pillar, pirate, razor, robot, rocket, rose, shark, skeleton, skis, snail, spider, stethoscope, tail, telescope, thumb, toilet, tweezers, vase, violin, volcano, wallet, whale, wig, worm.
	Experiment 2 only: anchor, angel, arm, arrow, axe, ball, balloon, banana, basket, bath, beard, bed, bedroom, bee, bell, belt, bird, bone, book, box, brain, bridge, brush, bucket, bus, butterfly, button, camel, camera, candle, castle, cat, chain, chair, cheese, cherry, church, cigar, cigarette, circle, circus, clock, clown, collar, comb, conductor, cork, cow, crack, cross, crown, curtain, devil, dog, door, duck, elephant, envelope, eye, fence, finger, fish, flag, flower, foot, fork, frog, fruit, garden, gate, grapes, guitar, hair, hammock, hat, heart, horse, hospital, house, iron, judge, kettle, key, king, kitchen, knot, ladder, leaf, leg, letter, library, lion, money, moon, mouse, mushroom, nose, nun, office, pencil, piano, picnic, picture, pig, pipe, plug, pocket, pond, pram, pyramid, radio, rake, road, roof, roots, saddle, sandwich, sausage, scissors, shadow, sheep, shirt, shoe, shorts, shower, slide, spoon, square, stamp, stool, strawberry, sun, sword, table, tent, ticket, tiger, tongue, tourist, tractor, tray, tree, triangle, trumpet, tunnel, umbrella, waitress, watch, weight, wheel, whistle, window.
	Both studies: drum, feather, map, nest, pear, submarine, tank, tie, waiter, witch.
Action	Experiment 1 only: bowl, brush, comb, cough, curl, curtsey, fall, fish, give, hatch, mail, mop, pet, row, salute, scoop, squeeze, surf, swat, sweat, throw, vacuum, whistle, zip.
	Experiment 2 only: bend, bite, bleed, blow, build, carry, catch, climb, cut, dance, dig, drink, drive, drop, float, fly, fold, kiss, knit, knock, laugh, lean, lick, light, march, melt, paint, pinch, post, pour, pray, pull, rain, read, ride, ring, roar, rock, shave, shoot, sink, skip, sleep, slide, smoke, sneeze, stir, stroke, swim, swing, tickle, touch, wash, wave, weave, weigh, yawn.
	Both studies: bark, beg, bounce, crawl, cry, dive, draw, drill, drip, eat, iron, juggle, jump, kick, kneel, open, peel, plant, play, point, push, rake, run, sail, sew, sing, sit, skate, ski, smile, snow, stop, type, walk, watch, water, write.

Appendix B

Characteristics of the pictures used in the object and action naming tasks

Indexes	Overall	
	Mean	SD
Familiarity		
Object	3.89	1.47
Action	3.99	1.40
Imageability		
Object	5.83	0.58
Action	4.24	0.58
Age-of-Acquisition		
Object	2.49	0.70
Action	2.56	0.66
Word Frequency		
Object	65.53	97.84
Action	80.87	100.69
Visual Complexity		
Object	3.48	1.33
Action	4.23	0.76

Chapter 3: Selective and Nonselective Inhibition of Competitors in Picture Naming

This chapter is an adapted version of: Shao, Z., Meyer, A. S., & Roelofs, A. (2013). Selective and nonselective inhibition of competitors in picture naming. *Memory & Cognition*, Advance online publication. doi:10.3758/s13421-013-0332-7.

CHAPTER 3: SELECTIVE AND NONSELECTIVE INHIBITION IN PICTURE NAMING

Abstract

In two experiments, we examined the relation between nonselective inhibition and selective inhibition in picture naming performance. Nonselective inhibition refers to the ability to suppress any unwanted response, whereas selective inhibition refers to the ability to suppress specific competing responses. The degree of competition in picture naming was manipulated by presenting targets along with distractor words that could be semantically related (e.g., a picture of a dog combined with the word *cat*) or unrelated (*tree*) to the picture name. The mean naming response time (RT) was longer in the related than in the unrelated condition, reflecting semantic interference. Delta plot analyses showed that participants with small mean semantic interference effects employed selective inhibition more effectively than participants with larger semantic interference effects. The participants were also tested on the stop-signal task, which taps nonselective inhibition. Their performance on this task was correlated with their mean naming RT but, importantly, not with the selective inhibition indexed by the delta plot analyses and the magnitude of the semantic interference effect. These results indicate that nonselective inhibition ability and selective inhibition of competitors in picture naming are separable to some extent.

CHAPTER 3: SELECTIVE AND NONSELECTIVE INHIBITION IN PICTURE NAMING

Introduction

A key component of the human ability to speak is the retrieval of words from the mental lexicon. This process, called *lexical access*, has been widely studied using a range of different paradigms, including analyses of speech errors in healthy and brain-damaged speakers (e.g., Badecker, Miozzo, & Zanuttini, 1995; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Goodglass, Kaplan, Weintraub, & Ackerman, 1976; Kay & Ellis, 1987), chronometric experiments (e.g., Schriefers, Meyer, & Levelt, 1990), brain imaging studies (e.g., Indefrey & Levelt, 2004; de Zubicaray, Wilson, McMahon, & Muthiah, 2001), and computational modeling (e.g., Foygel & Dell, 2000). This research effort has led to the development of detailed models of lexical access (e.g., Caramazza, 1997; Dell, 1986; Levelt, 2001; Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000; Roelofs, 1992). Although differing in important ways, most models agree that lexical access to a word proceeds in two steps, the retrieval of a syntactic representation of the word (often called the *lemma*) and the retrieval and encoding of the corresponding morpho-phonological representations.

Speaking is a goal-directed activity. Speakers do not emit random words at random times, but select words to achieve communicative goals. Thus, executive control must be involved in this process. Although there are a variety of conceptions of executive control processes (e.g., Baddeley, 1986; Posner & Petersen, 1990), they all agree that one important component of executive control is the ability to inhibit competing information (Miyake et al., 2000). During speaking, many thoughts may come to mind that are not to be expressed, and many words may be activated that are not included in the utterance because, for instance, they are in a language not shared by the interlocutor, or because they are too general or socially inappropriate. Intuition suggests that speakers need to inhibit such concepts and words. A number of recent empirical studies have suggested the involvement of inhibition in lexical access in monolingual and bilingual spoken word production (e.g., de Zubicaray et al., 2001; de Zubicaray, McMahon, Eastburn, & Wilson, 2002; de Zubicaray, McMahon, Eastburn, & Pringle, 2006; Guo, Liu, Misra, & Kroll, 2011; Misra, Guo, Bobb, & Kroll, 2012; Jackson, Swainson, Cunnington, & Jackson, 2001; Roelofs, Piai, & Garrido Rodriguez, 2011). Moreover, there is evidence that inhibition deficits contribute to the impaired word production of children with developmental language disorders, such as specific language impairment (e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Seiger-Gardner & Schwartz, 2008; Spaulding, 2010). In sum, there is some evidence that inhibition may contribute to the efficiency of word production.

It has been proposed that inhibition is not a unitary construct but can best be thought of as a set of closely related abilities (e.g., Castner et al., 2007; Friedman & Miyake, 2004; Krämer, Knight, & Münte, 2011; Nigg, 2000; Spaulding, 2010). In the literature, several taxonomies of types of inhibition have been proposed (e.g., Friedman & Miyake, 2004; Nigg, 2000). An important distinction is between top-down inhibitory control (e.g., Jackson et al., 2001; Green, 1998; Roelofs et al., 2011) and lateral inhibition within word planning levels (e.g., Berg & Schade, 1992; Harley, 1993; for an extensive discussion, see Aron, 2007). The present work concerns top-down inhibitory control, and specifically the distinction made by Forstmann et al. (2008) between “nonselective” and “selective” inhibition. Nonselective inhibition involves the top-down suppression of the planning and execution of any unwanted response. This type of inhibition is assumed to be involved in the stop-signal task, where participants prepare for a response but, upon presentation of a stop signal on a minority of trials, must refrain from executing it (e.g., Logan & Cowan, 1984). The inhibition is taken to be nonselective because evidence suggests that the planning of any unwanted response is suppressed (cf. Nigg, 2000). Selective inhibition involves the top-down suppression of specific strong competitors to a response, which are induced by external distractors. This type of inhibition is assumed to be involved in Stroop, Simon, and Eriksen flanker tasks (cf. Nigg, 2000). The inhibition is taken to be selective because evidence suggests that it is specifically applied to strongly competing responses, such as the responses activated in the incongruent, but not in the congruent condition of these tasks. Evidence from studies using Simon and Eriksen flanker tasks suggests that selective inhibition takes time to build up and, as Ridderinkhof and colleagues (Ridderinkhof, 2002; Ridderinkhof, Scheres, Oosterlaan, & Sergeant, 2005) have shown, therefore has a stronger effect on slower compared to faster responses.

Pennington (1997) found that performance on the Stroop task and the stop-signal task did not highly correlate, which suggests a distinction between selective and nonselective inhibition. This distinction is also supported by brain imaging studies (e.g., Castner et al., 2007; Krämer et al., 2011). For example, Krämer et al. (2011) found different ERP components as correlates for selective and nonselective inhibition. Similarly, Verbruggen, Liefooghe, and Vandierendonck, (2004) obtained behavioral evidence for a difference between these two types of inhibition. However, Miyake et al. (2000) used Stroop, anti-saccade, and stop-signal tasks in a latent variable analysis to explore executive functions and found a common underlying inhibition function for these three tasks (see also Friedman & Miyake, 2004). Moreover, based on findings from brain imaging studies, other researchers have argued that selective and nonselective inhibition share a common neural network (i.e., including the right inferior frontal cortex, see Forstmann et al., 2008; Van den Wildenberg et al., 2010). In sum, the evidence on whether or not a differentiation between selective and nonselective inhibition is warranted is inconsistent.

How might the distinction between selective and nonselective inhibition apply to word production? Much of the work on the role of inhibition in word production has concerned bilingual speakers. A common assumption is that bilingual speakers use inhibition to suppress words in the non-target language, either obligatorily (Abutalebi & Green, 2007; Costa, Hernández, & Sebastián-Gallés, 2008; Green, 1998; Guo et al., 2011; Misra et al., 2012; Jackson et al., 2001) or optionally (Roelofs et al., 2011; Verhoef, Roelofs, & Chwilla, 2009). Because of the routine engagement of inhibition in language control, bilingual speakers might outperform monolingual speakers in linguistic as well as non-linguistic tasks involving inhibitory control. This prediction has been borne out in some studies using the Simon and Eriksen flanker tasks engaging selective inhibition (Bialystok, Craik, Klein, & Viswanathan, 2004; Costa et al., 2008), but it has so far not been confirmed for other tasks requiring inhibition (Colzato et al., 2008). This suggests that bilingual speakers might primarily recruit selective inhibition in language control. However, a literature review by Hilchey and Klein (2011) revealed that many studies found no bilingual advantage in selective inhibition. A more robust finding is that bilingual individuals outperform monolingual speakers on both congruent and incongruent trials of Simon and flanker tasks, which suggests a bilingual advantage in nonselective rather than selective inhibition.

More central to the current research are studies of monolingual word production. Here top-down inhibition has been invoked to explain how speakers suppress unwanted information and minimize disfluencies (Engelhardt, Corley, Nigg,

& Fereirra, 2010) or select a response among a set of competitors (de Zubicaray et al., 2001, 2002). Several studies used interference paradigms, where participants had to name target pictures in the presence of distractor words (cf. Glaser & Düngelhoff, 1984; Roelofs, 1992, 2003; Schriefers et al., 1990), which were semantically or phonologically related or unrelated to the target. Given that in these tasks speakers have to suppress responses to highly salient competitors, selective inhibition may be involved. To the best of our knowledge, there is so far only one study, by Shao, Roelofs, and Meyer (2012), that explicitly addressed the role of nonselective inhibition in picture naming. In that study, we showed that individual differences in picture naming speed were related to the speakers' nonselective inhibition ability as measured through their performance in the stop-signal task. Taken together, the available results suggest that both selective and nonselective inhibition may play a role in monolingual naming. However, since each study only assessed one type of inhibition, nothing can be said about the relationship between the two types of inhibition in naming performance. The aim of the present study was to examine this relationship by assessing both types of inhibition in the same group of participants. We used an individual differences approach (see also Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Ridderinkhof, Band, & Logan, 1999) and examined whether participants with good, or poor, nonselective inhibition would also show good, or poor, selective inhibition, and we examined how the individuals' lexical access ability was affected by both types of inhibition.

The participants were tested in two tasks. One task was the stop-signal task, introduced by Logan and Cowan (1984). Here, the participants were instructed to perform a choice-response task. Occasionally a stop signal was presented to indicate that participants should stop any response. The timing of the stop signal varied across trials depending on the participant's performance on the preceding trial (see below for details). The second task was a picture-word interference task, where the participants named pictures accompanied by written distractor words that belonged to the same semantic category or to a different category as the target (e.g., target: dog, related distractor: *cat*, unrelated distractor: *tree*). A standard finding in the picture-word interference paradigm is that the response time (RT) is longer in the presence of same-category compared to unrelated distractors (e.g., Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Lupker, 1979; Lupker & Katz, 1981). The origin of this semantic interference effect is currently under debate. One account is that it arises during lemma selection (e.g., Levelt et al., 1999; Roelofs, 1992; Schriefers et al., 1990): A semantically related distractor receives activation from the target and is therefore a more potent competitor to the target than an unrelated distractor, which is not activated by the target (see Roelofs, 1992, 2003, for details). An alternative account is that the semantic interference effect occurs because the articulatory program derived for the written distractor enters the response buffer and must be removed for an overt response to the picture to occur. This process of removing the distractor representation from the buffer is assumed to take longer when the distractor is semantically related to the target than when it is unrelated (e.g., Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007).

On both accounts of the semantic interference effect, speakers may inhibit their response to the distractor, more so for semantically related than unrelated distractors. Their ability to do this (i.e., their selective inhibition ability) can be represented in a delta plot, which represents the size of the interference effect as a function of relative naming RT (De Jong, Liang, & Lauber, 1994; Ridderinkhof, 2002). To compute a delta plot, the cumulative distribution of RTs for each condition is divided into quantiles (e.g., 20% bins), and the interference effect (delta) for each quantile is plotted (see Figure 1). As Ridderinkhof (2002) has shown, in the absence of inhibition, delta increases across the quantiles, i.e., slower reactions are accompanied by larger effects. However, when selective inhibition is applied, this increase in effect size is counteracted. As inhibition requires time to build up, this leads to a decrease of the deltas and the slopes of the delta plot across quantiles (for reviews see Proctor, Miles, & Baroni, 2011; Van den Wildenberg et al., 2010). The slope of the slowest segment (e.g., the segment connecting the fourth and fifth quintile, q4-5 in Figure 1) appears to be most sensitive to selective inhibition ability (Forstmann et al., 2008). Therefore, this slope can be used to estimate the speaker's ability of specific inhibition. As shown in Figure 1 (right panel), strong inhibition of responses to semantically related distractors may even turn semantic interference into semantic facilitation (i.e., the delta of q5 and the slope of segment q4-5 have negative values).

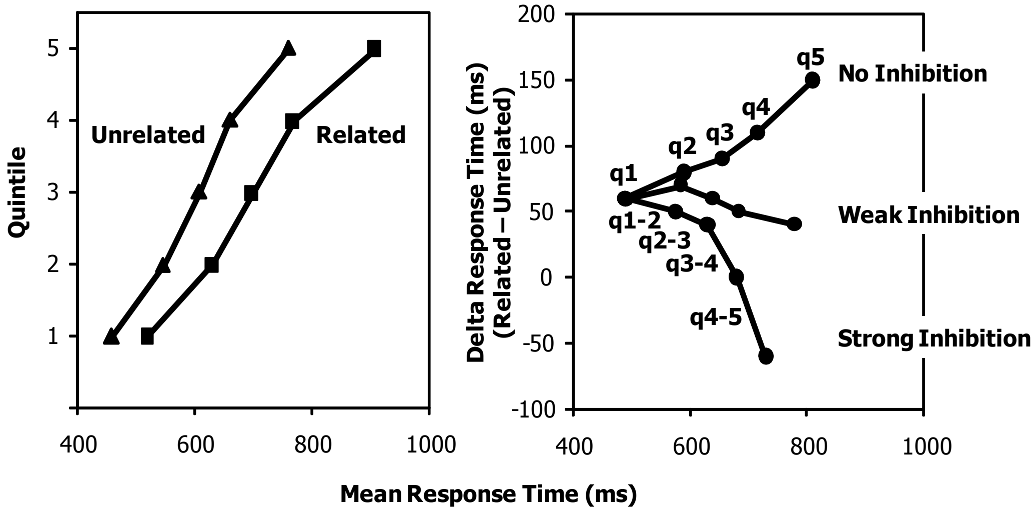

Figure 1. Left panel: cumulative distribution curves for response times in semantically related and unrelated conditions. Right panel: delta plot showing the condition differences (deltas) as a function of quintile (1-5) and amount of inhibition (no, weak, strong). q1, quintile 1, and so forth; q1-2 is the segment connecting quintiles 1 and 2, etc. (cf. Roelofs et al., 2011).

CHAPTER 3: SELECTIVE AND NONSELECTIVE INHIBITION IN PICTURE NAMING

We expected to replicate the semantic interference effect seen in earlier studies. We assessed the correlation between the magnitude of the semantic interference effect and the slope of the slowest delta segment across participants. Based on the results obtained by Roelofs and colleagues (2011), we expected that the larger the magnitude of the semantic interference effect, the steeper the slope of the slowest delta segment would be (see Figure 1). Such a relationship would indicate that the participants with smaller interference effects apply selective inhibition more effectively than participants with larger interference effects (see Proctor et al., 2011; Van den Wildenberg et al., 2010, for extensive discussion). Based on the results obtained by Shao and colleagues (2012), we expected that the participants' mean RT would be correlated with their stop-signal RT. This would indicate that good nonselective inhibition (i.e., inhibition of responses to both semantically related and unrelated distractors) contributes to fast reactions in the picture naming task. The most important question concerned the relationship between nonselective inhibition (indexed by the stop-signal RT) and selective inhibition (indexed by the slope of the slowest delta segment). If they reflect the same underlying inhibition ability, as suggested by Friedman and Miyake (2004), Forstmann et al. (2008), Miyake et al. (2000), Nigg (2000), and Van den Wildenberg et al. (2010), then a positive correlation should be found between the stop-signal RT and the slope of the slowest delta segment across participants. By contrast, the absence of such a correlation would suggest that nonselective and selective inhibition are separable to some extent (cf. Castner et al., 2007; Krämer et al., 2011; Pennington, 1997; Verbruggen et al., 2004).

CHAPTER 3: SELECTIVE AND NONSELECTIVE INHIBITION IN PICTURE NAMING

Experiment 1

Method

Participants. The study was carried out with sixty-four native Dutch speakers (6 men, *Mean age* = 33.78 years, range: 16 to 63 years[1]), selected from the participant pool of the MPI for Psycholinguistics. They participated in exchange for payment. All participants had normal or corrected-to-normal vision and normal hearing.

Picture-Word Interference Task. ***Materials and design.*** The materials consisted of 56 line-drawings of common objects adopted from the Snodgrass and Vanderwart (1980) corpus. The picture names were monosyllabic or disyllabic; the average log word-form frequency in the CELEX database was 1.25 /million (*SD* = 0.59), and the average age of acquisition was 6.76 years (*SD* = 1.54 years; Ruts et al., 2004). The pictures fitted into a virtual frame of 4 cm by 4 cm on the computer screen (2.29° of visual angle) and were shown on a white background in the center of the computer screen.

The pictures were combined with semantically related and unrelated distractor words. Most previous work using delta-plot analyses to examine selective inhibition has used Simon or flanker tasks with incongruent and congruent conditions rather than with distractors either present or absent. With distractors being present or absent, it is impossible to tell whether inhibition is selective or nonselective. That is, suppression could involve selective inhibition (i.e., only the response to the distractor is inhibited) or nonselective inhibition (i.e., any incorrect response, including that to the distractor, is inhibited). By using semantically related and unrelated distractors, it

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[1] The study was carried out in the Individual Differences in Language Processing Department at the Max Planck Institute for Psycholinguistics, where a systematic effort is made to involve participants of all ages and with diverse backgrounds in the research.

may be assessed whether inhibition is indeed selective (i.e., applied more strongly to semantically related than to unrelated distractors) or nonselective (i.e., applied equally strong to the semantically related and unrelated distractors).

In the semantically related condition, the pictures were combined with written distractor words from the same semantic category. Targets and distractors were unrelated in phonological form, i.e., they did not share the onset consonant(s) or rhyme. In the unrelated condition, the same pictures and distractor words were used, but they were recombined into semantically and phonologically unrelated pairs (see Appendix). Figure 2 shows two example stimuli. Each picture was also shown with two further semantically unrelated distractors, one of which was phonologically related to the picture. The effects of these distractors did not differ from each other and the corresponding trials are treated as filler trials here. The distractors were superimposed in the center of the pictures and were presented in black, in lower case Arial font of 26-point size.

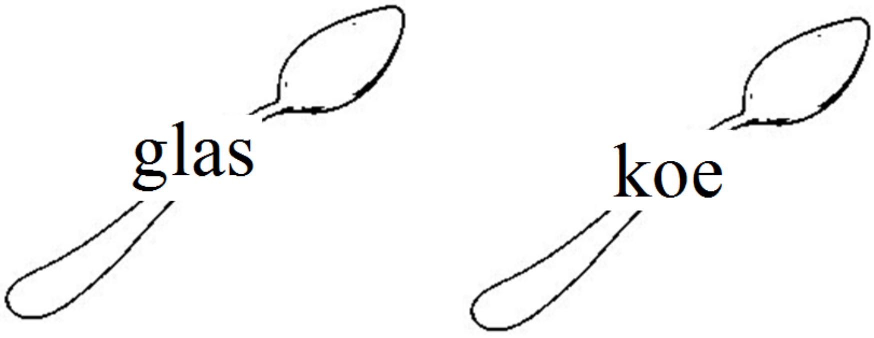

Figure 2. Example stimuli for the semantically related (left) and unrelated (right) conditions (target: *lepel* (*spoon*); distractors *glas* (*glass*), *koe* (*cow*)).

Fifty-six target pictures were combined either with semantically related or unrelated distractors, which led to a total of 112 items. These 112 items were evenly distributed across four blocks, such that each block contained 28 target items. In each block, each target picture was only shown once. In addition, 28 filler items were inserted into each block. The order of the trials within each block was pseudo-randomized, such that no more than three target pictures of the same condition appeared in succession, and consecutive pictures were not semantically or phonologically related. The order of the four blocks was rotated across participants.

Procedure. The participants were tested individually. At the beginning of the study, they were given a booklet showing the pictures and their names. They were asked to familiarize themselves with the materials and to use only the names in the booklet to refer to the pictures. Then they were handed a second booklet showing only the pictures and were asked to name them. Errors were immediately corrected by the experimenter. This familiarization phase was followed by the four test blocks, which were separated by short breaks. Participants were instructed to name the pictures aloud as fast and as accurately as possible.

On each trial of the test blocks, a fixation cross (+) was presented for 300 ms in the center of the screen. After a blank interval of 200 ms, a target-distractor compound was shown until the participant overtly responded, for a maximum of three seconds. The inter-trial interval was 500 ms.

Apparatus. A HP 8540P laptop with the software package Presentation® (Version 14.3, www.neurobs.com) was used to control the experiment. Naming RTs were recorded online using a voicekey but were later checked and where necessary corrected using the speech analyses program Praat (Boersma, 2001).

Data analyses. Responses were categorized as errors when speakers used object names that were different from those given in the picture booklet or when the response included a repair or disfluency or started with a filler word (e.g., "uh"). Errors were excluded from the RT analyses. To generate the delta plots, the RTs for each participant and distractor condition were sorted in ascending order and divided into RT quintiles (i.e., 20% bins). Then the mean RT and the average semantic effect for each condition and quintile were calculated. Following De Jong et al. (1994; see also Ridderinkhof, 2002), the slopes of the lines connecting the delta values for successive quintiles *x* and *y* were computed as follows:

$$\text{Slope }(x\,y) = \frac{\text{Delta (Quintile}\,y) - \text{Delta(Quintile}\,x)}{\text{Mean(Quintile}\,y) - \text{Mean(Quintile}\,x)}$$

Stop-Signal Task. ***Materials, design and procedure.*** The visual stimuli in the stop-signal task were a fixation cross, a square (1.5 by 1.5 cm) and a circle (1.5 cm in diameter). The auditory stimulus was a 750 Hz tone with duration of 75 ms.

On go-trials, the fixation cross (+) was presented in the middle of the screen for 250 ms and was immediately replaced by a square or a circle for a maximum of 1250 ms. Squares and circles were presented equally often in a random order. The participants should press the "/" key when they saw a circle and the "Z" key when they saw a square. They were instructed to respond as quickly as possible. The key press terminated the trial. On stop-trials, the tone was played as a stop signal shortly after the offset of the fixation cross. The participants were instructed to withhold their response when they heard the tone. Initially, the stop-signal delay (SSD) was set to 250 ms after the offset of the fixation cross. If the participant successfully inhibited the response on a given stop trial, the delay in the following stop trial was increased by 50 ms (making it harder to withhold the response), otherwise the delay was decreased by 50 ms.

There was a practice block of 32 trials, followed by three test blocks of 64 trials each. Each block included 75% go-trials and 25% stop-trials, presented in a random order. Following Verbruggen, Logan, and Stevens (2008), each participant's stop-signal RT was estimated by subtracting the mean SSD from the mean RT on go-trials.

Apparatus. The same laptop and experimental software were used as for the picture-word interference experiment. Sennheiser HD 201 headphones were used to present the tone.

Results

The results obtained from four participants were excluded from the analysis because they failed to follow the instructions in the stop-signal task. For the remaining participants the error rate on go-trials was 4.6%, the RT on go-trials was 687 ms, and the estimated stop-signal RT (SSRT) was 278 ms. The participants successfully withheld their response on 46% of the no-go trials. These values are similar to those found in earlier studies (e.g., Logan, Schachar, & Tannock, 1997; Shao et al., 2012).

Table 1 shows the average error rates and RTs in the semantically related and unrelated conditions of the picture-word interference experiment. As expected, the participants' responses were slower, by 41 ms, in the related than in the unrelated condition. This semantic interference effect was significant in analyses of variance using participants (t_1) and items (t_2) as random variables, $t_1(59) = 6.81$, $p < .001$, $t_2(55) = 5.22$, $p < .001$. More errors were made in the semantically related than in the unrelated condition, but this difference was statistically not reliable, $t_1(59) = 2.13$, $p < .05$, $t_2(56) = .63$, $p = .53$. To assess whether the semantic interference effect varied with test block, we submitted the RTs to a 4 x 2 (Block [1, 2, 3, 4] x Distractor Condition [semantically related, unrelated]) repeated-measures ANOVA. When using participants as random variable, there was neither a significant main effect of block, $F_1(3, 56) = .25$, $p = .87$, nor an interaction between block and distractor condition, $F_1(3, 56) = .55$, $p = .65$. When using items as random variables, there was a significant main effect of block, $F_2(3, 168) = 6.48$, $p < .001$, but no significant interaction between block and distractor condition, $F_2(3, 168) = .54$, $p = .65$.

Table 1

Results of Experiment 1: Mean Naming RT (in Milliseconds) and Error Rate per Distractor Condition. SD = Standard Deviation

Distractor Condition	Mean RT	SD	Error Rate (%)
Related	845	92	4.6
Unrelated	804	81	3.7

The average naming RT correlated positively with the stop-signal RT, $r = .28$, $p < .05$. As the average naming RT was based on the naming RT in the related and unrelated conditions, this correlation may be affected by the semantic interference effect. Therefore, we also correlated the naming RT in the unrelated condition only with the stop-signal RT, and found a similar correlation, $r = .26$, $p < .05$.

By contrast, there was no correlation between the stop-signal RT (indexing nonselective inhibition) and the slope of slowest delta segment (indexing selective inhibition), $r = -.01$, $p = .93$. In line with this finding, the magnitude of the semantic interference effect and the mean stop-signal RT were also not correlated, $r = .12$, $p = .18$. However, the magnitude of the semantic interference effect and the slope of slowest delta segment were correlated, $r = .63$, $p < .001$. Similarly, the magnitude of the semantic effect and the delta of the fifth quintile (i.e., the delta corresponding to q5 in Figure 1) were correlated, $r = .46$, $p < .001$. Figure 3 shows the scatter plots for these correlations.

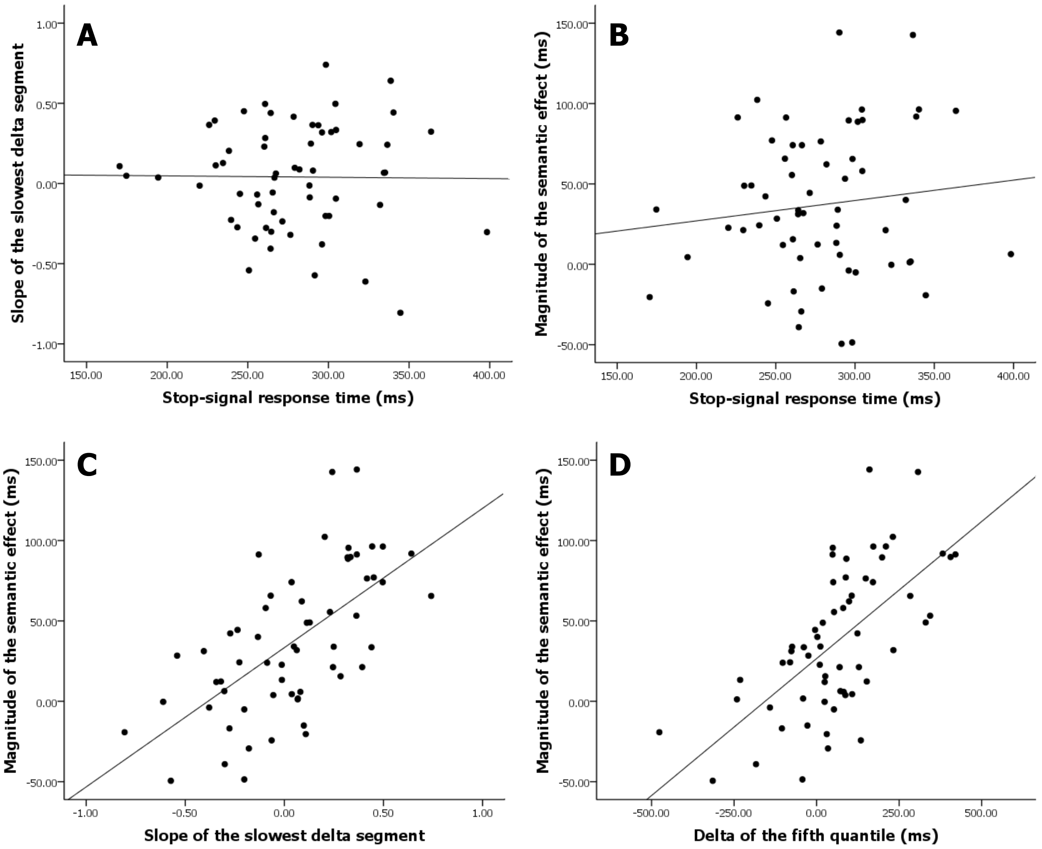

Figure 3. Results of Experiment 1: Scatter plots of the relationship between (A) the slope of the slowest delta segment and the stop-signal response time, (B) the magnitude of the semantic interference effect and the stop-signal response time, (C) the magnitude of the semantic interference effect and the slope of the slowest delta segment, and (D) the magnitude of the semantic interference effect and the delta of the fifth quintile.

In computing the delta plots, we sorted the picture naming RTs for each participant in ascending order, separately for each distractor condition. The quintiles were then defined separately for each distractor condition, and the magnitude of the semantic effect was computed by subtracting the related and unrelated conditions. Therefore a participant's responses to a given target picture in the related and unrelated condition were not always in the same quintile. A strength of the design of the picture-word experiment is that the same target pictures are used in the related and unrelated conditions. However, this matching of pictures is lost when the items are assigned to quantiles according to the participant's RT. To address this problem, we also computed item-based delta plots, by sorting in ascending order the response times for each item (instead of subject), for each distractor condition separately (cf. Roelofs, 2008). The quintiles, which now contained the same target pictures, were again defined separately for each distractor condition. The magnitude of the semantic interference effect and the slope of slowest delta segment were correlated, $r = .52$, $p < .001$, replicating the results of the subject-based delta plot analysis.

The strength of a correlation is constrained by the reliability of the measurements (e.g., Spearman, 1904, 1927). If reliability is not perfect, the observed correlation will be attenuated. To estimate the reliability of the stop-signal RT, we grouped the odd and even trials into separate sets, calculated the SSRT for each set, and computed the correlation between sets. This yielded a reliability estimate for the stop-signal RT of $r = .54$. To estimate the reliability of the size of the semantic interference effect, we computed the semantic effect size for each target picture and created two sets of targets, pairwise matched for effect size across the entire group of participants. We then computed the correlation across participants between the sizes of the semantic interference effect seen in the two sets of pictures. This yielded a reliability estimate of $r =.89$. To estimate the reliability of the slope of the slowest delta segment, we grouped the odd and even trials into separate sets, calculated each participant's slope of the slowest delta segment for each set of trials, and computed the correlations between sets. This yielded a reliability estimate of $r = .22$. Finally, to estimate the reliability of the naming RT, we grouped the odd and even trials into separate sets, calculated each participant’s naming RT for each set of trials, and computed the correlation between sets. This yielded a reliability estimate of $r = .98$. Next, we corrected the observed correlations r(x,y) for attenuation (i.e., the reliabilities of the measurements, r(x,x) and r(y,y)) by using the formula: Corrected r(x,y) = r(x,y) /√(r(x,x) r(y,y)), following Spearman (1904, 1927) and others (cf. Kline, 2000). Even after correcting for attenuation, the correlation between stop-signal RT and the slope of the slowest segment remained non-significant (corrected $r = -.03$, $p = .82$), and the same held for the correlation between the magnitude of the semantic effect and the stop-signal RT (corrected $r = .17$, $p = .19$).

The magnitude of the semantic interference effect, the slope of the slowest delta segment, and the SSRT all concern difference scores of measurements, for which the reliability will be lower than for the mean naming RT. Still, we found that certain difference scores correlated (i.e., the magnitude of the semantic effect and the slope of the slowest segment) whereas other difference scores did not correlate (i.e., the slope of the slowest delta segment and the SSRT), even after the corrections for attenuation. Moreover, the SSRT correlated with the naming RT but not with the magnitude of the semantic interference effect, even though the reliability of the naming RT and magnitude of the semantic effect was comparable. This suggests that the pattern of correlations is not driven by the reliability of the measurements.

The results of the correlation analyses indicate that the slope of the slowest delta segment (indexing selective inhibition ability) and the stop-signal RT (indexing nonselective inhibition ability) are not correlated. Moreover, the magnitude of the semantic effect (depending on selective inhibition) is correlated with the slope of the slowest delta segment, but not the stop-signal RT. This pattern of results was further assessed by conducting multiple regression analyses with the magnitude of the semantic interference effect as the criterion variable and the slope of the slowest delta segment, the SSRT, and the mean naming RT as predictor variables. Table 2 shows the results. The slope of slowest delta segment (indexing selective inhibition ability) was the only significant predictor of the magnitude of semantic interference effect, $R^2 = .46$, $F(3, 56) = 15.74$, $p < .001$. Stop-signal RT (indexing nonselective inhibition ability) and naming RT made no significant contribution.

Table 2
Results of Experiment 1: Results of the Multiple Regression Analysis with the Magnitude of Semantic Interference as Criterion Variable and the Slope of the Slowest Delta Segment, the Stop-Signal Response Time (SSRT), and the Mean Naming Response Time (RT) as Predictor Variables

Predictor Variables	Beta	SE	*t*-value
Slope of slowest delta segment	87.30	14.04	6.22**
SSRT	.13	.11	1.21
Mean naming RT	.02	.03	.74

Note: ** $p < .01$.

The results of the correlation and multiple regression analyses suggest that the contributions of selective and nonselective inhibition to word naming are to some extent separable. However, this conclusion critically rests on both significant correlations (i.e., between the slope of the slowest delta segment and the magnitude of the semantic effect) and non-significant correlations (i.e., between SSRT, on the one hand, and the slope of the slowest delta segment and the magnitude of the semantic interference effect, on the other hand). A second experiment was run in order to assess whether the pattern of correlations seen in Experiment 1 could be obtained again in a new sample of participants.

In Experiment 1, we tested a sample of participants who were quite heterogeneous in terms of age and level of education. Detailed analyses of the data did not reveal any systematic moderating effects of these variables, but the sample was not large and therefore subtle effects of age or education may have remained undetected. To address this concern, only young university students were invited to participate in Experiment 2.

Experiment 2

Method

Participants. The study was carried out with twenty-four Dutch undergraduate or graduate students (8 men, *Mean age* = 21.33 years, range: 19 to 34 years), selected from the participant pool of the MPI for Psycholinguistics. They participated in exchange for payment. All participants had normal or corrected-to-normal vision and normal hearing.

Tasks, Procedure, and Apparatus. The same picture-word interference task and stop-signal task as in the preceding experiment were used. Experimental design, procedure and apparatus were the same as in the preceding experiment.

Participants were tested individually. They were given the picture-word interference task first and then the stop-signal task. For the picture-word interference task, trials with any error (repairs, disfluency, stutter, and different answers) were excluded from the analysis of the RTs.

Results and Discussion

For the stop-signal task, the accuracy rate on go-trials was 98.57% and the RT on go-trials was 535 ms. Participants successfully withheld their response on 51% of the no-go trials, and the estimated stop-signal RT (SSRT) was 277 ms. Table 3 shows the average error rates and RTs in the semantically related and unrelated conditions of the picture-word interference task. As in Experiment 1, the participants' responses were slower, now by 32 ms, in the related than in the unrelated condition. This semantic interference effect was significant in analyses of variance using participants (t_1) and items (t_2) as random variables, $t_1(23) = 4.12$, $p < .001$, $t_2(55) = 2.40$, $p < .05$.

More errors were made in the semantically related than in the unrelated condition, but this difference was not significant, $t_1(23) = 1.78, p = .09$, $t_2(55) = .90, p = .37$.

Table 3

Results of Experiment 2: Mean Naming RT (in Milliseconds) and Error Rates per Distractor Condition. SD = Standard Deviation

Distractor Condition	Mean RT	SD	Error Rate (%)
Related	809	90	6.5
Unrelated	776	75	5.1

As in Experiment 1, the SSRT correlated positively with the average naming RT across all correct responses, $r = .44, p < .05$, and with the RT on correct trials in the unrelated condition, $r = .41, p < .05$. There was no correlation between the slope of the slowest delta segment (indexing selective inhibition ability) and the SSRT (indexing nonselective inhibition ability), $r = -.09, p = .36$. Furthermore, there was no correlation between the magnitude of the semantic interference effect (depending on selective inhibition) and the SSRT, $r = .09, p = .33$. However, the magnitude of the semantic interference effect was correlated with the slope of slowest delta segment, $r = .71, p < .001$, and with the delta of the fifth quintile, $r = .87, p < .001$. Figure 4 shows the scatter plots for these correlations.

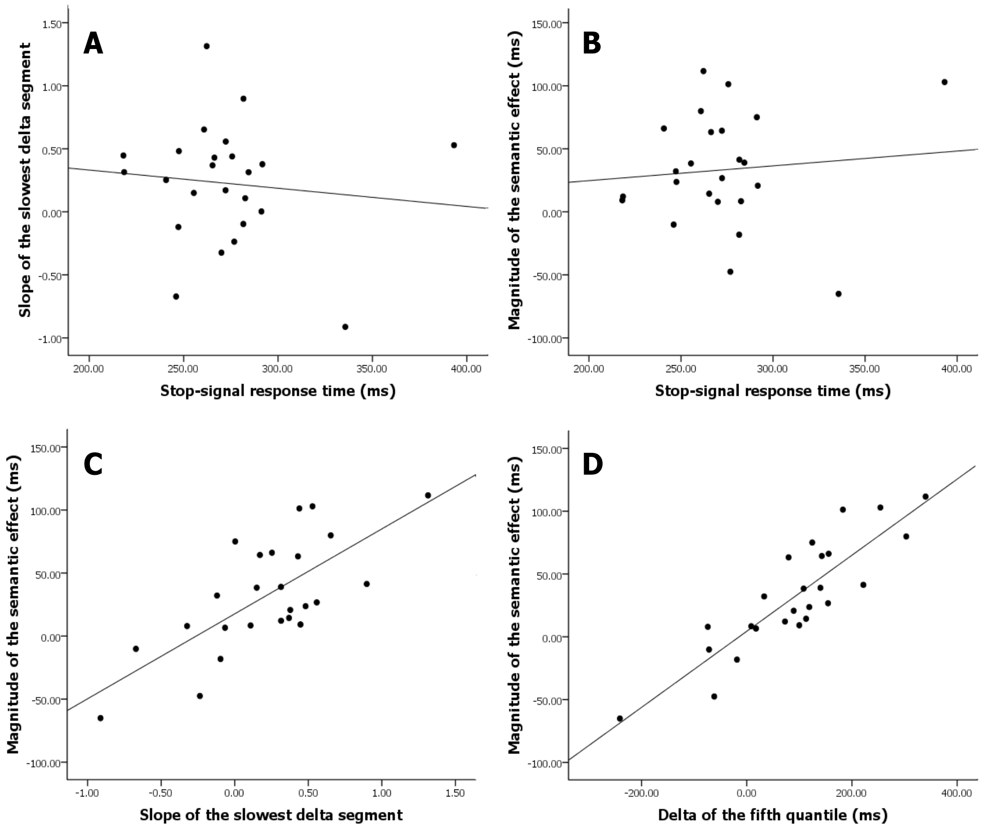

Figure 4. Results of Experiment 2: Scatter plots of the relationship between (A) the slope of the slowest delta segment and the stop-signal response time, (B) the magnitude of the semantic interference effect and the stop-signal response time, (C) the magnitude of the semantic interference effect and the slope of the slowest delta segment, and (D) the magnitude of the semantic interference effect and the delta of the fifth quintile.

We also computed item-based delta plots, by sorting in ascending order the naming RTs for each item (instead of subject), for each distractor condition separately, as in Experiment 1. The quintiles were again defined separately for each distractor condition, which now contained the same picture targets. The magnitude of the semantic interference effect and the slope of slowest delta segment were correlated, $r = .72$, $p < .001$, replicating what we found for the subject-based delta plot analyses. As in Experiment 1, the results of the correlation analyses indicate that the slope of the slowest delta segment and the stop-signal RT were not correlated. Moreover, the magnitude of the semantic interference effect was correlated with the slope of the slowest delta segment, but not with the stop-signal RT. This pattern of results was further assessed by conducting multiple regression analyses with the magnitude of the semantic interference effect as the criterion variable and the slope of the slowest delta segment, the SSRT, and the mean naming RT as predictor variables. Table 4 shows the results. The slope of the slowest delta segment (indexing selective inhibition ability) was the only significant predictor of the magnitude of semantic interference effect, $R^2 = .58$, $F(3, 20) = 9.31$, $p < .001$. Stop-signal RT (indexing nonselective inhibition ability) and naming RT made no significant contribution.

The results of the correlation and multiple regression analyses were similar to the results of Experiment 1, which corroborates the conclusion that the magnitude of the semantic interference effect only reflects selective inhibition (indexed by the slope of slowest delta segment), but not nonselective inhibition (indexed by the SSRT).

Table 4
Results of Experiment 2: Results of the Multiple Regression Analysis with the Magnitude of Semantic Interference as Criterion Variable and the Slope of the Slowest Delta Segment, the Stop-Signal Response Time (SSRT), and the Mean Naming Response Time (RT) as Predictor Variables

Predictor Variables	Beta	SE	*t*-value
Slope of slowest delta segment	64.35	14.01	4.59**
SSRT	.07	.21	.34
Mean naming RT	.14	.09	1.54

Note: ** $p < .01$.

General Discussion

The ability to inhibit responses seems often crucial for goal-directed, contextually appropriate behavior. Consequently, inhibitory control is widely regarded as a key component of executive control. However, it is far from clear how inhibitory control should be defined, whether it is useful to distinguish different types of inhibition, and if so, how they should be empirically distinguished, and finally, how domain-general inhibitory control processes affect specific types of behavior. In the current study we employed a standard psycholinguistic task – picture naming in the presence of distractors – and a standard inhibition task – the stop signal task – to explore, first, how inhibition affects performance in the linguistic task and, second, whether it is useful to distinguish two types of inhibition, namely selective and nonselective inhibition.

The study reported above yielded four key findings. First, we replicated the semantic interference effect seen in many earlier studies (e.g., Glaser & Düngelhoff, 1984; Lupker, 1979): The participants were slower to name targets accompanied by semantically related than by unrelated distractors. As discussed above, this semantic interference effect has been allocated at the level of lexical selection (e.g., Levelt et al., 1999) or articulatory buffering (e.g., Mahon et al., 2007). Discriminating between these accounts was not a goal of the present study.

Second, the participants differed substantially in the magnitude of the semantic effect. Delta plot analyses showed that the larger the semantic interference effect for a participant, the steeper the slope of the slowest delta segment. Since such a pattern has only been shown once before for picture-word interference in a study of bilingual naming (Roelofs et al., 2011), obtaining it in a study of monolingual naming is of importance in its own right. The finding confirms that the slope of the slowest delta segment indexed selective inhibition: Participants inhibited responses to semantically related distractors more strongly than responses to unrelated distractors.

A third finding was that the overall RT in the naming task was correlated with the stop-signal RT in the stop-signal task, replicating Shao et al. (2012, Chapter 2). The stop-signal RT is not an indicator of absolute processing speed but a difference score indicating how quickly planned responses can be stopped. Participants with short stop-signal RTs had overall shorter naming RTs than participants with longer stop-signal RTs.

A correlation between stop-signal RT and naming RT was observed in two earlier studies (e.g., Shao et al., 2012, Chapter 2; Xue, Aron, & Poldrack, 2008); the present study is the first to use the picture-word interference paradigm. In Chapter 2, we found, as in the present study, that the participants' overall RT in object and action naming was positively correlated with their stop-signal RT. The correlation between stop-signal RT and naming RT was somewhat stronger than in the present study. A likely reason for this is that the picture names were harder to retrieve in the earlier study, where we used items of lower name frequency, and where the participants were not familiarized with the pictures and their names before the experiment, Ex-Gaussian analyses of the RT distributions in the earlier study demonstrated that inhibition was more consistently engaged in action naming than object naming, presumably because the action pictures were more complex and triggered more incorrect responses than the object pictures[2]. The function of nonselective inhibition is to suppress the activation of any irrelevant responses activated by the pictures. However, given that pictures presumably only activate semantically related responses, the study did not allow us to determine whether the inhibition was indeed nonselective.

Our final, perhaps most important finding is that stop-signal RT (indexing nonselective inhibition) was not correlated with the slope of the slowest delta segment (indexing selective inhibition) and the magnitude of the semantic interference effect (depending on selective inhibition), even after correcting for attenuation (i.e., the

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[2] In the present study, the number of trials per condition was too low for ex-Gaussian analyses.

reliability of the measurements). In evaluating this null-result, it is important to keep in mind that stop-signal RT did correlate with the overall naming RT, as just discussed. Apparently, the ability to stop any irrelevant response to a target is different from the ability to quickly suppress the response to a specific, semantically related distractor. This suggests that the inhibition indexed by the stop-signal RT is indeed nonselective, that is, applied equally to semantically related and unrelated competitors. Consequently, nonselective inhibition reduces general interference during picture naming but has no effect on the magnitude of the semantic interference effect.

In sum, our results illustrate how a domain-general executive control process like inhibition can affect performance in a linguistic task. They also illustrate how the effects of closely related executive control processes can be separated: We demonstrated that selective and nonselective inhibition affected the naming performance of the participants in the picture-word interference task in different ways.

Our results imply that it is useful to distinguish between selective and nonselective inhibition. Taking account of the distinction between selective and nonselective inhibition is not only important for studies of inhibitory control per se, but may also be useful for considering the function of inhibitory control in language processes. As mentioned in the Introduction, although the role of top-down inhibition during language production processes has been increasingly noticed (de Zubicaray et al., 2001, 2002), the differentiation of types of inhibition has been neglected. For example, de Zubicaray and colleagues (2001, 2002) examined inhibition using picture naming with distractors, without distinguishing between selective and nonselective inhibition. However, the present results suggest that distractor effects only reflect selective inhibition.

Future research should consider the roles of different types of inhibition may play during language processing. This should not only be done for normal adult language performance, as assessed in the present study, but also for impaired language performance. Recent research suggests that inhibition is often deficient in individuals with specific language impairment (e.g., Henry et al., 2012; Im-Bolter et al., 2006; Seiger-Gardner & Schwartz, 2008; Spaulding, 2010). However, it is not clear which type of inhibition is affected. Specific language impairment (SLI) is a severe disorder of language acquisition and use in children who otherwise develop normally. The language disorder may persist into adulthood. The characteristics of the impaired language performance in SLI are quite variable, but common characteristics include a delay in starting to talk in childhood, deviant production of speech sounds, a restricted vocabulary, slow and inaccurate picture naming, and the use of simplified grammatical structures, including omission of articles and plural and past tense endings (see Leonard, 1998, for a review).

Seiger-Gardner and Schwartz (2008) compared the performance of children with SLI and typically developing children (on average 9-year old) in a picture-word interference task using spoken distractor words. Stronger semantic interference was observed in the SLI than in the control group (108 ms vs. 43 ms, respectively). This was taken as evidence that children with SLI were less effective in suppressing semantic alternatives. The results from the delta-plot analysis in the present study are consistent with this view. According to Seiger-Gardner and Schwartz (2008), “If children with SLI have a suppression mechanism deficiency, their ability to suppress irrelevant information in non-linguistic tasks should be equally poor” (p. 546). However, the results of the present study show that this generalization from the magnitude of semantic interference to other task situations may not be warranted. In our study, the ability of selective inhibition indexed by the delta-plot analysis was not correlated with the ability of nonselective inhibition indexed by the stop-signal task. Still, picture naming RTs were generally longer for the SLI than the typically developing group, which was attributed by Seiger-Gardner and Schwartz (2008) to general slowing. The current results, in particular the correlation between stop-signal RT and picture-naming RT, suggests that this slowing of picture naming may reflect a difference in nonselective inhibition. In line with this interpretation of the picture naming RTs in SLI, Spaulding (2010) observed inhibition weaknesses in pre-school children with SLI compared to typically developing controls in a type of stop-signal task as well as a task requiring the suppression of distractors. To conclude, evidence suggests that both selective and nonselective inhibition may be deficient in children with SLI compared to typically developing controls. Nevertheless, selective and nonselective inhibition may dissociate, as shown by the present study.

Conclusions

To summarize, the present study suggests separability of nonselective inhibition (as indexed by stop-signal RT) and selective inhibition (as indexed by the slope of slowest delta segment) in picture naming. The former is proposed to suppress any competing response and the latter is proposed to suppress specifically alternatives that are strong competitors to a correct response. Future theoretical and empirical work on the involvement of inhibition in picture naming and, more generally, in word production should take the distinct functions of inhibition into account.

Appendix

Target names of pictures and semantically related and unrelated distractors, followed by English translations in parentheses.

Target names	Related distractors	Unrelated distractors	Target names	Related distractors	Unrelated distractors
anker (anchor)	loopplank (gangway)	caravan (trailer)	kerk (church)	moskee (mosque)	schoffel (hoe)
arm (arm)	voet (foot)	boter (butter)	ketel (kettle)	pan (frying pan)	standbeeld (statue)
bank (couch)	dressoir (sideboard)	paleis (palace)	kok (cook)	bakker (baker)	wapen (weapon)
beer (bear)	tijger (tiger)	mandarijn (mandarin)	kruis (cross)	driehoek (triangle)	vetplant (succulent plant)
berg (hill)	weide (meadow)	struik (bush)	lepel (spoon)	glass (glass)	koe (cow)
bezem (broom)	dweil (rag)	pan (frying pan)	maan (moon)	planeet (planet)	driehoek (triangle)
bom (bomb)	mijn (mine)	vijl (file)	masker (mask)	schmink (makeup)	piano (piano)
boom (tree)	struik (bush)	glass (glass)	motor (motorbike)	auto (car)	tank (tank)
borstel (brush)	gel (gel)	mitrailleur (machine gun)	orgel (organ)	piano (piano)	tijger (tiger)
bot (bone)	spier(muscle)	helicopter (helicopter)	pijl (arrow)	speer (spear)	loopplank (gangway)
broek (pants)	trui (sweater)	rolschaats (roller-skate)	pop (doll)	teddy beer (teddy bear)	knikker (marble)
bus (bus)	tram (tram)	weide (meadow)	schaar (scissors)	lijm (glue)	pijp (pipe)
cactus (cactus)	vetplant (succulent plant)	ploeg (plow)	schip (ship)	onderzeër (submarine)	mijn (mine)
citroen (lemon)	mandarijn (mandarin)	ventiel (valve)	sigaar (cigar)	pijp (pipe)	moskee (mosque)
fluit (flute)	hoorn (horn)	teddy beer (teddy bear)	slak (snail)	worm (worm)	behang (wallpaper)
fontein (fountain)	standbeeld (statue)	oor (ear)	step (scooter)	rolschaats (roller-skate)	kantoor (office)
gordijn (curtain)	behang (wallpaper)	cello (cello)	ster (star)	meteoor (meteor)	hoorn (horn)
hamer (hammer)	vijl (file)	dweil (rag)	tas (bag)	koffer (suitcase)	lijm (glue)
hand (hand)	oor (ear)	marmot (marmot)	tent (tent)	caravan (trailer)	band (tire)

harp	trompet	spier	tol	knikker	slinger
(harp)	(trumpet)	(muscle)	(top)	(marble)	(garland)
hengel	dobber	teen	tractor	ploeg	koffer
(fishing rod)	(float)	(toe)	(tractor)	(plow)	(suitcase)
hoed	pet	beker	vaas	pot	trompet
(hat)	(cap)	(mug)	(vase)	(jar)	(trumpet)
jurk	blouse	onderzeër	varken	koe	auto
(dress)	(blouse)	(submarine)	(piglet)	(cow)	(car)
kaas	boter	rechthoek	vinger	teen	shampoo
(cheese)	(butter)	(rectangle)	(finger)	(tor)	(shampoo)
kam	shampoo	planeet	vlag	wapen	meteoor
(comb)	(shampoo)	(planet)	(flag)	(weapon)	(meteor)
kameel	aap	bakker	vork	servet	schmink
(camel)	(ape)	(baker)	(fork)	(napkin)	(makeup)
kan	beker	glijbaan	wiel	band	speer
(can)	(mug)	(slide)	(wheel)	(tire)	(spear)
kanon	tank	bed	zaag	tang	voet
(cannon)	(tank)	(bed)	(saw)	(tongs)	(foot)

Chapter 4: Selective Inhibition and Naming Performance in Semantic Blocking, Picture-Word Interference, and Color-Word Stroop Tasks

This chapter is an adapted version of: Shao, Z., Roelofs, A., Martin, R., & Meyer, A. S. (submitted). *Selective inhibition and naming performance in semantic blocking, picture-word interference, and color-word Stroop tasks.*

CHAPTER 4: THE EFFECT OF SELECTIVE INHIBITION ON REDUCING SEMANTIC INTERFERENCE

Abstract

The present study examined the influence of selective inhibition on reducing interference in three naming tasks: semantic blocking, picture-word interference, and color-word Stroop interference. Delta plots were used to determine the size of the interference effects as a function of response speed. Selective inhibition was indexed by the increase in the size of the interference effect for the bin of longest naming response times (RT) relative to the preceding faster bin. This increase was expressed in the slope of the delta plots. For all three naming tasks, mean naming RTs were significantly longer in the interference condition than in a control condition. The slopes of the interference effects for the longest naming RTs correlated with the magnitude of the mean semantic interference effect in both the semantic-blocking task and the picture-word interference task, suggesting that selective inhibition was involved to reduce the interference from strong semantic competitors in picture naming. However, there was no correlation between the slopes and the mean interference effect in the Stroop task, suggesting absence of selective inhibition in this task. Additionally, no correlation was found between stop-signal RT (indexing nonselective inhibition) and the magnitude of interference effects, suggesting that nonselective inhibition was unlikely to be involved in reducing the semantic interference during naming. We conclude that selective inhibition, but not nonselective inhibition, can be invoked by either one single explicit competitor or strong implicit competitors.

CHAPTER 4: THE EFFECT OF SELECTIVE INHIBITION ON REDUCING SEMANTIC INTERFERENCE

Introduction

In order to communicate effectively in everyday life speakers must select the right words at the right time. A key component of word production is lexical access, that is, the retrieval of words from the mental lexicon given the concepts to be expressed. Lexical access has been widely studied, and this research effort has led to the development of detailed models of the linguistic encoding processes involved in lexical access (e.g., Caramazza, 1997; Dell, 1986; Levelt, 2001; Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000; Roelofs, 1992). Word production is a goal-directed activity, as speakers typically aim to achieve a communicative goal with their utterances. Therefore, the question arises of how the processes of lexical access interface with cognitive control processes so that speakers usually do not emit just any words but words serving their intentions.

One of the reasons why selecting the right word at the right time is not trivial is that often several concepts and their associated words are simultaneously active in the speakers mind. The competing concepts and words can, for instance, pertain to related ways of thinking about the same object (e.g. "sofa" vs. "couch"), to objects to be referred to in succession in a sentence (which can lead to anticipatory speech errors, such as “throw the window through the clock”, Fromkin, 1973), to objects just mentioned by an interlocutor, or to different names associated with a single object in the mind of a multilingual speaker.

How speakers select appropriate words, those expressing their intentions, is still not completely clear. However, there is accumulating evidence pointing to an important role of inhibitory processes during lexical selection. For instance, several studies suggest that bilingual speakers outperform monolingual speakers on non-linguistic and linguistic tasks tapping inhibitory processes. In particular, mean response time (RT) in some tasks is shorter for bilingual than monolingual individuals. It has been proposed that these differences arise because bilingual speakers need to use inhibition to suppress their non-target language whenever they speak or listen to speech (e.g., Guo, Liu, Misra, & Kroll, 2011; Misra, Guo, Bobb, & Kroll, 2012; Jackson, Swainson, Cunnington, & Jackson, 2001; Roelofs, Piai, & Garrido Rodriguez, 2011). This leads to superior inhibition ability in bilingual as compared to monolingual speakers. There is also evidence that deficits in inhibition ability may contributed to the impaired word production of children with specific language impairment (e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Seiger-Gardner & Schwartz, 2008; Spaulding, 2010). Finally, and most importantly for the present purposes, the results of several recent studies suggest the involvement of inhibitory control during object naming in a native language by adults (e.g., de Zubicaray et al., 2001; de Zubicaray, McMahon, Eastburn, & Wilson, 2002; de Zubicaray, McMahon, Eastburn, & Pringle, 2006; Shao, Roelofs, Meyer, 2012; Shao, Meyer, & Roelofs, 2013).

However, there is disagreement regarding the concept of inhibition. Several authors distinguish different components of inhibition supporting response selection in different types of conflicting situations. Two components are often studied (e.g., Castner, et al., 2007; Forstmann, et al., 2008; Krämer, Knight, & Münte, 2011; Spaulding, 2010). One component is called response suppression or nonselective inhibition and serves to suppress the execution of planned actions. This type of inhibition is considered to be nonselective because it is applied to stop any incorrect or inappropriate response. Nonselective inhibition is often assessed using the stop-signal task (Logan & Cowan, 1984), where participants prepare for a response, but have to refrain from executing it upon presentation of a stop signal. The timing of the stop signal varies across trials depending on the performance of the participant on the preceding trials. How quickly participants can stop their responses is used as an indicator of nonselective inhibition speed.

Another component of inhibition is referred to as interference control or selective inhibition. It is specifically recruited to suppress responses induced by strong competitors to a target response. Selective inhibition is usually measured using tasks such as the Stroop or Flanker task, where strongly competing responses are induced by distractors in an incongruent condition but not in a neutral or congruent condition. An important characteristic of selective inhibition, which sets it apart from nonselective inhibition, is that it takes time to build up and therefore has a stronger effect on slow than on faster responses (e.g., Ridderinkhof, 2002; Ridderinkhof, Scheres, Oosterlaan, & Sergeant, 2005; for reviews see Proctor, Miles, & Baroni, 2011; Van den Wildenberg et al., 2010).

In two earlier studies, we examined whether we could separate the contributions of selective and nonselective inhibition to picture naming. In the first study (Shao, Roelofs, & Meyer, 2012, Chapter 2) speakers named pictures of objects and actions and performed the stop signal task. Analyses of the correlations of the participants' speed on the three tasks suggested that nonselective inhibition was involved in naming, more so in action than in object naming as suggested by the RT distribution analyses (i.e. ex-Gaussian analysis; see Chapter 2 for details). There we speculated that action pictures were generally more complex than object pictures and evoked more alternative responses so that nonselective inhibition played a more important role in action than in object naming.

In the second study (Shao, Meyer, & Roelofs, 2013, Chapter 3), we used a picture-word interference task, which required participants to name target pictures in the presence of semantically related or unrelated distractor words. A robust finding in this paradigm is that mean naming RT is longer in the semantically related than in the unrelated condition (e.g., Glaser & Düngelhoff, 1984; Roelofs, 1992, 2003; Schriefers et al., 1990). The origin of this semantic interference effect is still under debate. One explanation is that it arises early during the naming process, namely during the selection of an appropriate lexical response: Semantically related distractors receive extra activation from the targets and therefore compete more strongly with the targets than unrelated distractors (see Roelofs, 1992, 2003, for details). Another explanation is that the effect arises late, during an articulatory buffering stage, close to articulation onset: The written distractor word activates the associated articulatory program, which is entered into an output buffer. The articulatory program activated in response to the distractor word must be removed from the output buffer so that the articulatory program for the response to the target picture can be executed. The removal of the articulatory program of the distractor is assumed to take longer when target and distractor are semantically related than when they are unrelated (e.g., Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). Both accounts assume that semantically related distractors generate more interference than unrelated ones. One might therefore expect selective inhibition to be applied specifically to related distractors.

We expected that naming latencies would be longer in the semantically related than in the unrelated condition. More importantly, we examined the magnitude of the interference effect as a function of response speed. To this end, we generated plots of the size of the interference effects (delta plots) by first dividing the cumulative distribution of RTs for each condition into quintiles and then plotting the size of the interference effect (delta) for each quintile (see also De Jong et al., 1994;

Ridderinkhof, 2002). When no selective inhibition is applied, the size of the interference effect increases across quintiles (e.g., Ridderinkhof, 2002). Thus, slower reactions are accompanied by larger effects. When selective inhibition is applied, the interference effect is attenuated, and, importantly, more so for slow than for fast responses. This is because selective inhibition requires time to build up. Therefore the slope based on interference effect in the slowest naming RT segment relative to that in preceding bin can be used to estimate an individual's inhibition ability (for further discussion, see Forstmann et al. (2008) and Van den Wildenberg et al. (2010)).

In our study, we found that the size of the participants' interference effects was predicted by the slope of the delta plot for the slowest reactions. In other words, participants with good selective inhibitory control (expressed as a shallow slope of the delta plot) showed a weaker interference effect than participants with poorer selective inhibitory control (expressed as a steeper slope). In addition to the picture-word interference tasks, the participants carried out the stop-signal task. We found that the participants’ performance on the stop-signal task was correlated with their naming RT in the unrelated condition (and the average across both condition) of the picture-word interference task, but not with the slopes of the slowest segments of the delta plot. This demonstrates that selective and nonselective inhibition can be dissociated to some extent (see also Roelofs et al., 2011).

In the picture-word interference paradigm different amounts of interference are induced by distractor stimuli that are presented at the same time as the targets. In the present study, we investigated whether selective inhibition would also be recruited in a naming task without such overt distractor stimuli, when strongly competing responses are activated through the prior experience of the participant in the experiment. All earlier studies of selective inhibition we know of induced different degrees of competition among responses by presenting different types of visual stimuli, which either did or did not feature distracting information. For instance, in the Simon task the stimuli (e.g., a circle and a square) are presented on the right- or left-hand side of a computer screen, and participants have to respond to one stimulus (e.g., the circle) by pressing a left button and to the other stimulus (the square) by pressing the right button. RT is usually shorter when the stimulus occurs on the same side as the correct response button (e.g., the circle is presented on the left-hand side of the screen, the congruent condition) than when stimulus and response sides differ (e.g., the circle is presented on the right-hand side of the screen, the incongruent condition), even though the stimulus location is irrelevant to the task. Similarly, in the Eriksen flanker task participants have to respond to a letter (e.g., S or H) that is flanked by distractor letters on each side (e.g., incongruent SSHSS or congruent SSSSS) by pressing a left button in response to one target letter (e.g., S) and a right button in response to the other target letter (i.e., H). RT is longer in the incongruent than congruent condition. In the picture-interference task, the stimuli are pictures with superimposed written distractors. Studies of selective inhibition using non-linguistic tasks, such as the Simon and Eriksen flanker tasks, found that the interference (i.e., incongruent vs. congruent) was reduced for relatively long RTs. In particular, the slopes of interference in the delta plots became shallower for the participants with more efficient inhibition ability, especially for the longest RTs (for the Simon task, see De Jong et al., 1994; for the Eriksen flanker task, see Wylie et al., 2009). Thus, in all of these tasks, conflict was introduced by a mismatch between relevant and irrelevant stimulus dimensions. In other words, distracting information was always explicitly presented. This also held for the linguistic picture-word interference studies by Roelofs et al. (2011) and Shao, Meyer et al. (2013, Chapter 3).

CHAPTER 4: THE EFFECT OF SELECTIVE INHIBITION ON REDUCING SEMANTIC INTERFERENCE

In the present study, we examined whether selective inhibition in linguistic tasks, requiring picture naming, is also recruited when strongly competing responses are activated in the absence of overt distracting information. To this end we used the semantic blocking paradigm (e.g., Belke, Meyer, & Damian, 2005; Damian, Vigliocco, & Levelt, 2001; Kroll & Stewart, 1994; Schnur et al., 2009). In this paradigm participants repeatedly name small sets of objects. In homogeneous test blocks, they all belong to the same semantic category (e.g., they are all animals or they are all vehicles). In heterogeneous blocks, they belong to different categories. A robust finding is that participants are slower to name the objects in homogeneous than in heterogeneous blocks. This semantic context effect probably arises during the selection of the object name: In related sets, the object names activate each other (perhaps via shared features or links to a shared superordinate unit), which delays the selection of the object names, compared to the unrelated sets, where the items do not activate each other (Abdel Rahman & Melinger, 2007, 2011; Belke, 2008; Belke et al., 2005; Damian et al., 2001; Kroll & Stewart, 1994; see Oppenheimer, Dell, & Schwartz, 2010, for a slightly different view). Thus, the cause of the semantic blocking effect may be similar to that of the semantic interference effect, namely competition between semantically related concepts or the associated words. If selective inhibition is invoked in naming whenever there are strongly competing responses, there should be evidence for its engagement in the semantic blocking task. By contrast, if selective inhibition is only involved when speakers deal with a specific physically present distractor word, no such evidence should be seen.

In the present study, the same group of participants was tested in three naming experiments and performed the stop-signal task. The first naming experiment was a picture-word interference experiment, similar to the experiment in Chapter 3, but using new materials. We expected to replicate the pattern seen in this earlier study: There should be a semantic interference effect, the size of which should correlate with the participants' selective inhibition ability, indicated by the slope of the delta plot for their slowest responses. Furthermore, the participants’ performance on the stop-signal task should correlate with their naming RT in the unrelated condition, but not with the size of the semantic interference effect.

In the second naming experiment, we used the semantic blocking paradigm. The same picture materials were used as in the picture-word interference experiment. We expected to obtain a semantic blocking effect, i.e., longer picture naming RTs in the semantically related than in the unrelated sets. If selective inhibition is engaged in this task, the mean size of the participants' interference effects should depend on their inhibitory control ability. We should then again obtain a correlation between the mean effect sizes and the slopes of the delta plot for the slowest RTs. Furthermore, the effect sizes and slopes should not correlate with the performance on the stop-signal task which is a measure of nonselective inhibition.

Finally, in the third naming experiment, we used the classic Stroop task, where participants named the color in which congruent or incongruent color words or a row of number symbols was printed. This task is often seen to be closely related to the picture-word interference paradigm, as it also involves the selection of a target (the name of the color of the ink) in the presence of the potent competitor (the color word, e.g., Roelofs, 2003). However, previous research conducting RT distributional analyses has suggested that participants in the color-word Stroop task may not use selective inhibition (Lamers, Roelofs, & Rabeling-Keus, 2010; Pratte, Rouder, Morey, & Feng, 2010), although other studies of Stroop task performance obtained evidence for the employment of selective inhibition (Bub, Masson, & Lalonde, 2006; Sharma, Booth, Brown, & Huguet, 2010). Thus, the use of selective inhibition in the Stroop task varies between studies. The absence of evidence for selective inhibition in some Stroop experiments suggests that speakers do not necessarily use inhibition when strong competitors are present, but that the use of inhibition is optional (cf. Roelofs et al., 2011; Verhoef, Roelofs, & Chwilla, 2009). If selective inhibition is involved in the present Stroop experiment (Bub et al., 2006; Sharma et al., 2010), one would expect to see similar results as for the picture-word interference paradigm: There should be an interference effect, the size of which should depend on the participants' inhibitory control ability, indexed by the slope of the slowest segment of the delta plots. In contrast, if selective inhibition is not involved (Lamers et al., 2010; Pratte et al., 2010), the magnitude of the mean interference effect should not correlate with the slope of the slowest delta segment.

Given that the same group of participants was tested in all experiments, we could explore the consistency of their performance across tasks. We should observe high correlations between two picture naming tasks in terms of naming latencies and the magnitude of semantic interference effect. In addition, if selective inhibition is involved in the Stroop task, we should find correlations between the participants' performance in the Stroop task and picture-word interference task. If selective inhibition is not involved, the correlations should be absent.

Method

Participants

The study was carried out with twenty-five undergraduate or postgraduate students (nine men, *Mean age* = 21.16 years, range: 18 to 27 years). They were recruited using the participant pool of the Max Planck Institute for Psycholinguistics Nijmegen. All participants were native speakers of Dutch and had normal or corrected-to-normal vision and normal hearing. They participated in exchange for payment.

The participants were tested individually. Half of the participants carried out the semantic blocking task first, followed by the Stroop task, the picture-word interference task and the stop-signal task; and the other half began with the picture-word interference task, followed by the stop-signal task, the semantic blocking task and the Stroop task. Thus, in both groups, linguistic and executive control tasks alternated. There were short breaks between the tasks.

Semantic Blocking task

Materials and design. The materials consisted of 16 line-drawings of common objects adopted from the Snodgrass and Vanderwart (1980) corpus, drawn from four categories (animals, furniture, tools, and body parts, listed in Appendix). All picture names were monosyllabic. The average log word-form frequency in the CELEX database was 1.52 /million (*SD* = 0.73), and the average age of acquisition was 5.5 years (*SD* = 1.60 years; Ghyselinkck, De Moor, & Brysbaert, 2000). All drawings fitted into a virtual frame of 4 cm by 4 cm (2.29° of visual angle) and were shown on a white background in the center of the computer screen.

There were four homogeneous and four heterogeneous sets of pictures. Each homogeneous set featured the four members of one of the four semantic categories. Each heterogeneous set featured one member of each category. The picture names in a set were unrelated in phonological form, sharing neither the onset nor the rhyme. Each of the eight sets was tested in a separate test block. In each block, the four items were shown six times each in a cyclic fashion, i.e., the four items were shown once, then they were all shown again for a second time, then for a third time, and so on. In generating the test cycles care was taken that the last item of a cycle was not the same as the first item of the next cycle. During the experiment, homogeneous and heterogeneous blocks alternated. Their order was counterbalanced across participants according to a Greco-Latin square design.

Procedure. At the beginning of the task, the participants were given a booklet showing the pictures and corresponding names. They were asked to familiarize themselves with the materials and to use only the names in the booklet to refer to the pictures. Then they were handed a second booklet showing only the pictures and were asked to name them. Any errors were corrected by the experimenter. This training continued until the participants had named all pictures once without making an error. The familiarization phase was omitted in the group of participants who had already performed the picture-word interference task.

On each trial of the test blocks, a fixation cross (+) was presented for 300 ms in the center of the screen. After a blank interval of 200 ms, a picture was presented until the participant responded, for a maximum of 3000 ms. The intertrial interval was 1000 ms.

Data analyses. Responses were categorized as errors when participants used different names from those given in the picture booklet or when the response included a repair or disfluency. Errors were excluded from the analyses of naming latencies.

Apparatus. All tasks were administered using a HP 8540P laptop. The software package Presentation® (Version 14.3, www.neurobs.com) was used to control the experiment. Naming RTs were recorded online using a voicekey but were later checked and where necessary corrected using the speech analyses program Praat (Boersma, 2001).

Picture-Word Interference Task

Materials and design. The same 16 pictures were used as in the semantic blocking task. The distractor words were the names of the pictures. The same linguistic materials were used in both experiments so that the two experiments only differed in whether or not distractor pictures where physically present (as written words) during the object naming task. The distractors were superimposed in the center of the pictures and presented in black in lower case font Arial at a size of 26-point.

There were two conditions, featuring semantically related or unrelated distractor-target pairs, respectively. Each of the 16 pictures was shown three times in each condition. In the semantically related condition, each picture was combined with the names of each of the other three members of the same category. In the unrelated condition, each picture was presented in combination with three different unrelated distractors (one from each of the three non-target semantic category). In total, the experiment consisted of 192 trials, distributed across four test blocks of 48 trials each.. Across all test blocks, each object name was used three times as a related distractor and three times as an unrelated distractor. The items were pseudo-randomized to make sure that the same item or the same distractor did not occur on the successive trials. The order of the four testing blocks was rotated across participants. Note that the two naming experiments were matched for number of trials and in each experiment, each item was tested six times each in the semantically related and in the unrelated condition.

Procedure. The participants were first familiarized with the materials as described above. The familiarization phase was omitted in the group of participants who had already carried out the picture-word interference task. On each trial of the test blocks, a fixation cross (+) was presented for 300 ms in the center of the screen. After a blank interval of 200 ms, a target-distractor compound was shown until the participant responded, for a maximum of three seconds. The intertrial interval was 1000 ms.

Stroop Task

Materials and design. The stimuli consisted of three Dutch color words, BLAUW (blue), GROEN (green), and ROOD (red), and a string of five number symbols (#####) printed in one of the three colors blue, green, and red. There were three conditions: congruent, incongruent, and neutral. In the congruent condition, the words were presented in the corresponding color (e.g., ROOD printed in red ink); in the incongruent condition, the words were presented in a different color (e.g., GROEN presented in red ink); and in the neutral condition, the symbol string was presented in one of the three colors. Each color was presented eight times in each condition, which leads to a total of 24 trials in each condition. The stimuli were presented in 66-point lowercase Lucida Console font.

On each trial, a fixation cross was presented in the screen center for 500 ms, followed by the stimulus word or string for 1000 ms. Then a black screen was presented until the participant responded, for up to 2000 ms. Participants were instructed to name the color of the ink as quickly as possible. Incorrect responses were excluded from the RT analyses. The naming RT difference between the incongruent and neutral condition was used to index the strength of the Stroop interference effect.

Stop-Signal Task

Materials, design and procedure. The visual stimuli were a fixation cross, a square (1.5 by 1.5 cm), and a circle (1.5 cm in diameter). The auditory stimulus was a 750 Hz tone with a duration of 75 ms.

On go-trials, the fixation cross (+) was presented in the middle of the screen for 250 ms and was immediately replaced by a square or a circle for a maximum of

1250 ms. Squares and circles were presented equally often in a random order. The participants should press the "/" key when they saw a circle and the "Z" key when they saw a square. They were instructed to respond as quickly as possible. The key press terminated the trial. On stop-trials, the tone was played as a stop signal shortly after the offset of the fixation cross. The participants were instructed to withhold their response when they heard the tone. The stop-signal delay (SSD) was initially set to 250 ms after the offset of the fixation cross. If the participant successfully inhibited the response on a given stop trial, the SSD on the following stop trial was increased by 50 ms, otherwise it was reduced by 50 ms.

There was a practice block of 32 trials, followed by three test blocks of 64 trials each. Each block included 75% go-trials and 25% stop-trials, presented in a random order. Following Verbruggen et al. (2008), each participant's stop-signal RT (SSRT) was estimated by subtracting the mean stop-signal delay across all trials from the mean RT on go trials. Short SSRTs indicate that participants can stop their responses relatively late during response preparation and are indicative of good inhibitory control.

Results

The data obtained from one participant were lost due to technical problems. Table 1 summarizes the error rates and response latencies in all tasks.

Table 1

Mean Naming RT (in Milliseconds) and Error Rates per Condition for the Semantic Blocking (SB) Task, the Picture-Word Interference (PWI) Task, the Stroop Task and Go-trials of the Stop-Signal task. SD = Standard Deviation

Task	Condition	Naming RT		Error Rate (%)	
		Mean	SD	Mean	SD
SB	Homogenous	576	55	6.8	6.1
	Heterogeneous	552	48	5.9	5.2
PWI	Related	688	82	2.0	1.6
	Unrelated	662	67	1.1	1.4
Stroop	Incongruent	818	138	5.3	4.0
	Congruent	682	109	2.5	3.9
	Neutral	658	87	2.5	4.8
Stop-signal	Go trials	611	164	2.1	2.3

Semantic blocking task. An analysis of variance was carried out on the log-transformed error rates with one between-participants factor (order, whether the semantic blocking task was administered before or after the PWI task) and two within-participants factors, context (homogenous, heterogeneous), and cycles (with six levels). There was no main effect of order, $F(1, 23) = 2.57$, $p = .12$, or context $F(1, 23) = 2.50$, $p = .13$, but there was an interaction between order and context, $F(1, 23) = 4.90$, $p < .05$, indicating that the participants who were given the semantic blocking task first made more errors in the homogenous blocks than in the heterogeneous blocks (4.6 % vs. 2.4 %), whereas the participants who were first tested on the PWI task showed similar error rates in both conditions (3.5 % vs. 2.6 %).

In the corresponding analysis of variance on the naming RTs, there was no main effect of order, $F(1, 23) < 1$. As expected, there was a significant main effect of context, $F(1, 23) = 16.41$, $p < .001$, with the average naming RT being longer (by 24 ms) in the homogenous than in the heterogeneous condition. There was also a significant main effect of cycle, $F(5, 110) = 2.59$, $p < .05$ (see Figure 1). There was no interaction of context and cycle, $F < 1$.

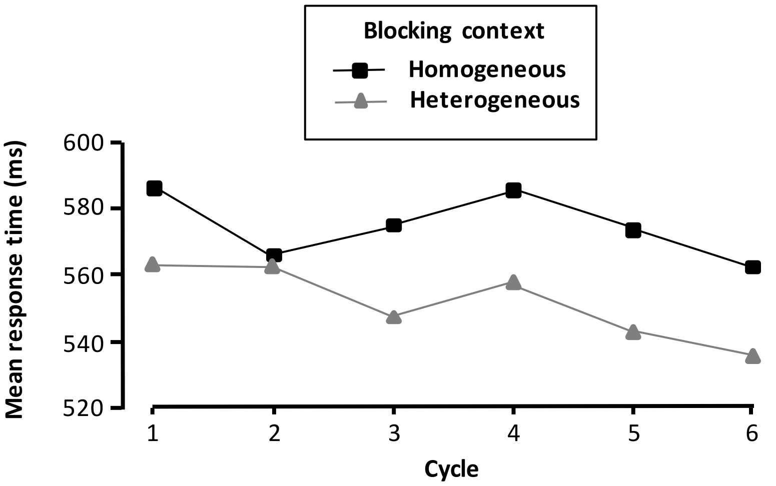

Figure 1. Mean naming reaction time (in milliseconds) in the semantic blocking task over cycles, broken down by blocking context.

As explained in the Introduction, the interference effect should generally increase with the naming RTs, i.e., relatively slow average responses should be accompanied by larger interference effects than faster average responses. However, this trend can be counteracted when selective inhibition is recruited. Therefore, participants with good inhibitory control ability should show a less pronounced increase in the interference effect with increasing naming latencies than participants with weaker inhibitory control, and this should lead to a smaller overall interference effect. To assess this hypothesis, delta plots were computed as described above.

For illustrative purposes, participants were assigned to a smaller or a larger effect group according to their performance in the task (above or below the median value of the magnitude of the interference effect). As shown in Figure 2a, these smaller and larger effect groups showed similar effect sizes for the fastest reactions, but the group differences increased with increasing average RTs. The steeper slope of the delta plot in the large effect group indicates that the participants were less efficient in recruiting selective inhibition than the participants in the small effect group.

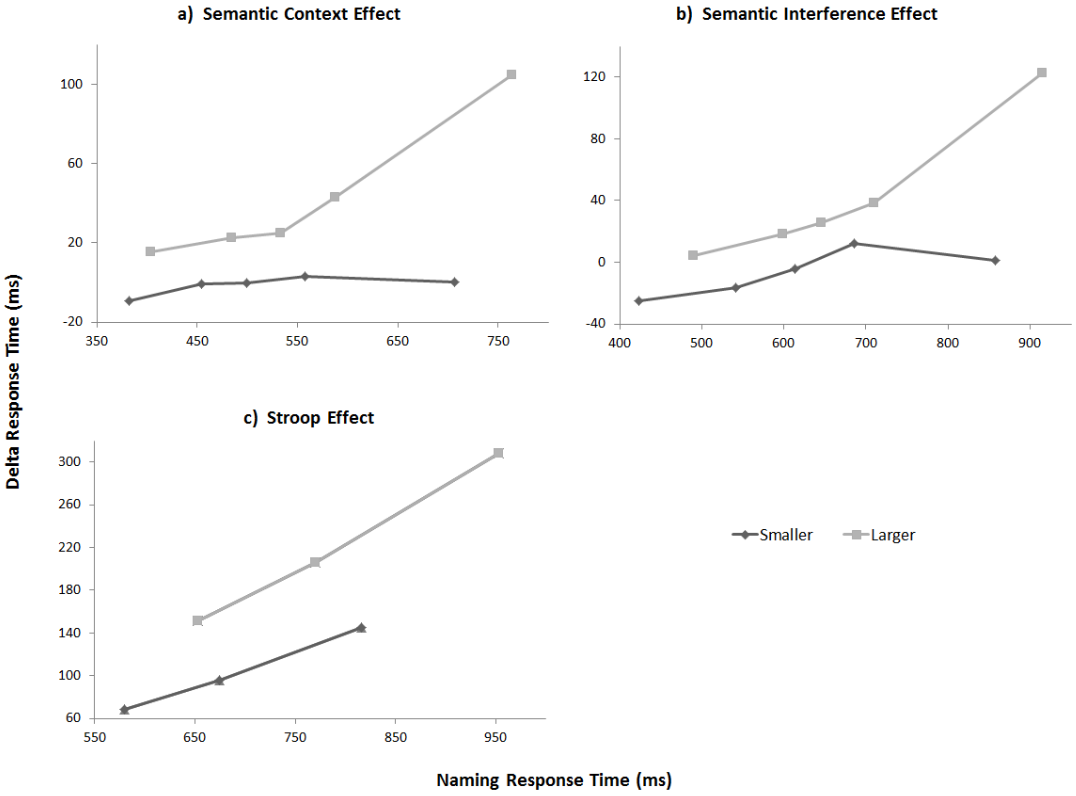

Figure 2. Delta plots for the interference effect in the small and large effect groups in a) the semantic blocking task, b) the picture-word interference task and c) the Stroop task. The response times on the horizontal axis are the mean response times in the two conditions used to compute each delta value.

To quantify the relationship between the strength of the interference effect and the participants' inhibitory control ability, we correlated the slopes of the slowest delta segment and the magnitude of the interference effect for each participant. We found a significant correlation, $r = .42$, $p < .01$ (see Figure 3a).

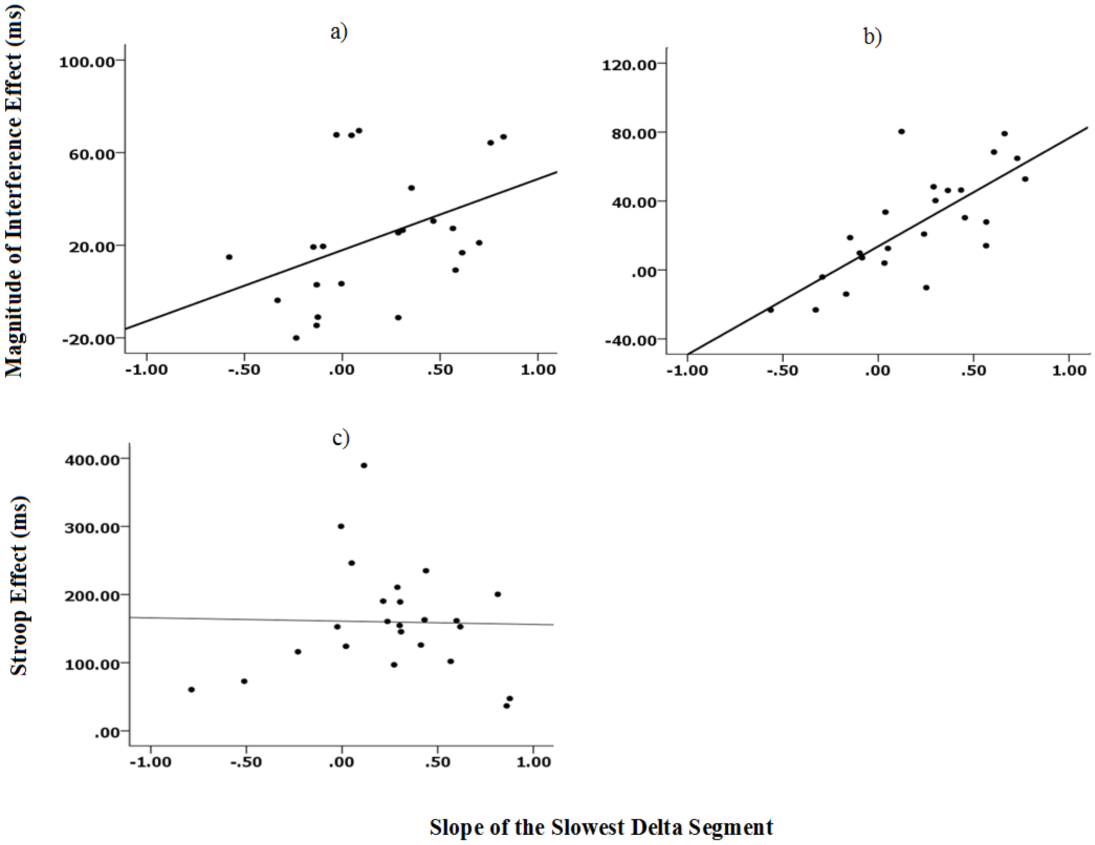

Figure 3. Scatter plots of the correlations between the magnitude of the interference effects and the slopes of the slowest delta segments in a) the semantic blocking task, b) the PWI task and c) the Stroop task.

Picture word interference task. For the PWI task, an analysis of variance was computed on the log-transformed error rates with one between-participants factor (order, whether the picture-word interference task was carried out before or after the blocking task) and two within-participants factors, distractor (semantically related, unrelated) and blocks (four levels). Only the main effect of distractor was significant, $F(1, 23) = 9.82$, $p < .01$, with participants making more errors in the semantically related than in the unrelated condition (see Table 1).

In the corresponding analysis of the naming RTs, there was a main effect of distractor, $F(1, 23) = 21.61$, $p < .001$, with the average RT being slower by 26 ms in the semantically related than in the unrelated condition. None of the other main effects and none of the interactions were significant[3].

As for the semantic blocking task, we computed the delta plots relating the size of the interference effects to the average naming RTs and correlated the slowest slopes and the magnitude of interference effect for each participant. We found a significant correlation $r = .75$, $p <.001$ (see Figure 3b).

Stroop task. The log-transformed error rates in the three conditions (congruent, incongruent, neutral) were compared in a one-way repeated measures analysis of variance. This did not yield a significant effect, $F(2, 22)= .17$, $p = .85$. However, the average naming latencies differed significantly across conditions, $F(2, 22) = 63.97$, $p < .001$. As shown in Table 1, naming RTs were longest in the incongruent condition and shortest in the neutral condition. Planned comparison showed that the RT difference between the incongruent and neutral condition was significant, $t(23) = 9.73$, $p < .001$, as was the difference between the congruent and the neutral condition, $t(23) = 1.98$, $p = .06$. Delta plots[4] were computed as for the two picture naming latencies, though bins for tertiles of latencies were used instead of bins for quintiles because fewer observations were available. There was no correlation between the size of the Stroop interference effect and the slope of the delta-plot for the slowest reactions, $r = .08$ (Figure 3c).

Stop signal task. For the stop-signal task, the error rate on go-trials was 2.13% and the estimated stop-signal RT (SSRT) was 283 ms. These values are similar

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[3] Naming latencies of the picture naming tasks were submitted to analysis using a mixed effect model (Quené & van den Bergh, 2008). Fixed effects were conditions and experiment blocks/cycles, and random effects were participants and items. The results confirmed the interference effects (semantic blocking, $F(1, 4263) = 28.54$, $p < .001$; picture-word interference: $F(1, 3973) = 11.58$, $p < .01$).

to those found in previous studies (e.g., Logan, Schachar, & Tannock, 1997; Shao et al., 2012).

Correlations among measures. In addition to analyzing the participants' performance in each task, we assessed the consistency of their performance across tasks. Table 2 shows the correlations of the latencies in the unrelated conditions of the three naming tasks and in the Stop-Signal task. As expected, the correlation between the naming latencies in the picture-word interference task and in the blocking task was high. There was also a high correlation between the naming latencies in the picture word interference and the Stroop task.

Unexpectedly, the picture naming latencies did not correlated significantly with the SSRT. This was true for the overall naming latencies as well as for the latencies in the individual conditions[5]. However, marginally significant correlations were seen when only the first block in unrelated condition of each naming experiment was considered: for the semantic blocking task, r = .33, p = .06 in the heterogeneous condition; and for the picture-word interference task, r = .30, p = .08 in the unrelated condition. Additionally, the naming latencies in the Stroop task did not correlate with SSRT, r = -.10, p = .64 in the incongruent condition, r = .05, p = .80 in the congruent condition, and r = .12, p = .59 in the neutral condition.

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[5] For the semantic blocking task, r = -.17, p = .42 in the homogenous condition, and r = .03, p = .90 in the heterogeneous condition. For the picture-word interference task, r = -.08, p = .72 in the semantically related condition, and r = .05, p = .82 in the unrelated condition.

Table 2.
Correlations between Naming Latencies in Control Condition of Semantic Blocking (SB), Picture-Word Interference (PWI) and Stroop Task and Stop-Signal Reaction Time (SSRT)

	SB	PWI	Stroop	SSRT
SB		.62**	.31	.03
PWI			.58**	.05
Stroop				.12
SSRT				

Note: ** $p < .01$.

Table 3.
Correlations between the Magnitude of Interference Effects (Mean) and Correlations between the Slopes of the Delta Plots for the Slowest naming segments of Semantic Blocking (SB), Picture-Word Interference (PWI) and Stroop Task

		SB		PWI		Stroop	
		Mean	Slopes	Mean	Slopes	Mean	Slopes
SB	Mean		.42*	.70**	.45*	.18	.09
	Slope			.70**	.97**	.17	.22
PWI	Mean				.75**	.24	.21
	Slope					.06	.32
Stroop	Mean						-.02
	Slope						

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

Next, we examined the relationship in the strength of the interference effects in the three naming tasks. Table 3 shows the correlations of the interference effects in the naming tasks, as well as the correlations of the slopes of the delta plots for the slowest responses. As expected, the correlation between the size of the participants' semantic interference effect and the size of their semantic blocking effect was high, *r*

= .70, $p < .001$. The correlations of both effects to the Stroop effect were much lower and not significant (see Table 3). Furthermore, the slowest slopes in the two picture naming tasks were likewise highly correlated, $r = .97$, $p < .001$, but neither of them correlated with the slopes in the Stroop task. Finally, there was no correlation between the slowest slopes and the SSRT, for picture-word interference task $r = -.28$, $p = .18$, and for semantic block task $r = -.23$, $p = .27$.

Discussion

In each of the three experiments reported above we obtained the interference effects typically seen in the respective paradigms: In the picture-word interference experiments, the participants were slower to name the pictures when they were accompanied by related as compared to unrelated distractors. In the semantic blocking experiments, the participants were slower to name the pictures in homogeneous than in heterogeneous blocks; and in the Stroop experiment, they were slower to name the color of ink when the stimulus was an incongruent color word than when it was a row of number symbols. However, demonstrating these well-known effects was not the main goal of the study. Instead we aimed to compare the participants' performance across tasks and, most importantly, determine whether there was evidence for the involvement of selective and nonselective inhibition in each of them.

Comparing the two picture naming tasks, we found that the participants' naming latencies in the unrelated conditions were highly correlated. Given that the same materials were used in both tasks this is perhaps not too surprising, but it does show that the speakers varied in average naming latencies and that their performance was consistent across the tasks. This is in line with earlier results demonstrating high correlations in the naming latencies for object and action pictures (cf. Chapter 2). In other words, there appear to be faster and slower namers (cf. Laganaro, Valente, &

Perret, 2012). Furthermore, the naming latencies of the individual items also showed a consistency across tasks. We found a high correlation between overall naming latencies in the semantic blocking task and the picture-word interference task for each item, $r = .62$, $p < .01$, and for the latencies in the unrelated conditions of the tasks, $r = .53$, $p < .05$.

In an earlier study (cf. Chapter 3), we had observed the naming RT in the unrelated condition of a picture word interference experiment correlated with the performance in the stop-signal task, indicating the involvement of nonselective inhibition in naming. We did not replicate this finding here, neither for the unrelated condition of the picture-word interference experiment nor for the heterogeneous condition of the blocking experiment. However, as reported above, we found marginally significant correlations between SSRT and the naming latencies in the first test block of each experiment. Thus, as participants became more and more familiar with the materials and the task, nonselective inhibition became a less important predictor of their RT. Why this was the case needs to be assessed in further research. One possibility is that the correlation between SSRT and naming RT is sensitive to the novelty of stimuli and therefore correlations became weaker after multiple repetitions. For instance, Dimoska and Johnstone (2008) manipulated the probability of the stop signal in the stop-signal task and found the difference between rare and frequent stop signals may be confounded by the novelty effects. Future research is needed to assess this possibility.

Returning to the comparison of the two picture naming experiments, we found that the participants not only performed very similarly in terms of their latencies in the unrelated conditions, but also experienced similar amounts of interference. Thus, a person who had a relatively strong or weaker semantic blocking effect also had a relatively strong or weaker interference effect in the picture-word interference task. This implies that the speakers' ability to cope with semantic interference was consistent across these two naming tasks.

Turning to the role of selective inhibition in naming, we found strong evidence for the involvement of selective inhibition in the picture word interference experiment: The participants with strong interference effects showed steeper slowest slopes than the participants with weaker interference effects. This replicates an earlier finding (cf. Chapter 3). Importantly, a similar pattern was seen in the semantic blocking experiment. Again, there was a significant correlation between the size of the participants' interference effects and the slope of the slowest segment in the delta plot. Moreover, the correlations between the slopes of the slowest delta segments in the two tasks was high, r = .97. This pattern suggests that selective inhibition is a trait-like ability, manifesting similarly in the two naming tasks. The result also implies that the presence of a single highly salient distractor is not a necessary condition for observing the recruitment of selective inhibition in a naming task. Instead, selective inhibition is also recruited when several responses are highly co-activated because they are part of a small response set or have recently been produced. Though the current study is, to our knowledge, the first to demonstrate directly that selective inhibition can be involved in absence of overt distractor stimuli that induce different degrees of conflict, the result fits in well with the observation of Biegler and colleagues (2008) that patients with a deficit in inhibiting verbal representations showed a greatly exaggerated semantic blocking effect.

Interestingly, we found no evidence for the engagement of selective inhibition in the Stroop task, in agreement with Lamers et al. (2010) and Pratte at al. (2010) but different from Bub et al. (2006) and Sharma et al. (2010). For the Stroop task, there was no correlation between the size of the participants' mean interference effects and the slopes of their slowest delta segments in the delta plots, and there was no correlation of these slopes with the corresponding slopes in the picture naming tasks. Recall that we had used bins based on quintiles of the latencies for the picture naming task and bins used on tertiles for the Stroop task. However, when tertiles were used for all three tasks, we still did not obtain significant correlations of the slowest slope of the Stroop task with the corresponding slopes in any of the other tasks, ($r = .27$, $p = .10$ for the correlation with the slopes in picture word interference task, $r = -.22$, $p = .15$, for the correlation with the slopes in the semantic blocking task)[6] .

The absence of evidence for the engagement of selective inhibition in the Stroop task is remarkable since this task is often viewed as being closely related to the picture-word interference task and as a prototypical interference task (e.g., Glaser & Düngelhoff, 1984). However, a result similar to ours was obtained by Lamers et al. (2010) and Pratte et al. (2010). Using delta plot analyses, Pratte et al. found evidence for the involvement of selective inhibition in the Simon task, but not in the Stroop task. Pratte et al. maintain that selective inhibition (indexed by delta plot slopes) is engaged only when stimuli and responses involve a horizontal spatial dimension, as present in the Simon and Eriksen flanker tasks, but absent in the Stroop task. However, this account fails to explain why evidence for selective inhibition, as indexed by delta plots, is obtained in picture-word interference (Roelofs et al., 2011; Shao et al., 2013; and the present study), where stimuli and responses do not involve a horizontal spatial dimension. Moreover, Bub et al. (2006) and Sharma et al. (2010)

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[6] For the two picture naming tasks, the slopes of the slowest delta segments were significantly correlated with the magnitude of interference effect when using tertile analyses, $r = .65$, $p < .001$ in the picture-word interference task, and $r = .35$, $p < .05$ in the semantic blocking task.

obtained evidence for selective inhibition in the Stroop task, again without concerning a horizontal spatial dimension. This suggests that a horizontal spatial dimension is not the critical factor triggering selective inhibition. Whereas evidence for selective inhibition is consistently obtained in picture-word interference tasks (Roelofs et al., 2011; Shao et al., 2013; and the present study), its involvement in Stroop task performance is somewhat more variable (i.e., present in Bub et al. 2006, and Sharma et al., 2010, but absent in Lamers et al., 2010, and Pratte et al., 2010). It is unclear why the engagement of selective inhibition in the Stroop task is variable. At the very least, the variability suggests that selective inhibition is not necessarily triggered by competition but that its engagement is optional (Roelofs et al., 2011; Verhoef et al., 2009).

We had predicted that the size of the interference effects should not be correlated with the participants' performance in the stop-signal task. This is indeed the result we obtained. It suggests that selective and nonselective inhibition are separable to some extent. However, since the SSRT did not correlate with the overall naming latencies, or the latencies in the unrelated conditions of the naming tasks either, the absence of correlations with the interference effects should be seen as merely suggestive.

Finally, one may ask what the present results imply for the origin and location of interference effects in the picture-word interference and in the blocking paradigm. The semantic blocking effect is generally allocated at the level of lexical selection (e.g., Belke, Meyer et al., 2005; Damian et al., 2001; Howard et al., 2006; Kroll & Stewart, 1994). Our main finding, that selective inhibition was recruited in the blocking task, is compatible with this view. However, Oppenheimer et al. (2010) proposed that implicit learning may contribute to the effect. In our blocking experiment, the interference effect did not build up across the cycles within a block, as would be predicted under the implicit learning account. The semantic interference effect in the picture-word paradigm is currently viewed either as an effect arising during the selection of a lexical response (e.g., Roelofs, 1992, 2003) or as arising during the exclusion of the articulatory program corresponding to the distractor from an output buffer (e.g., Finkbeiner & Caramazza, 2006). Our finding that selective inhibition is recruited in the picture-word interference task is compatible with both views. However, whereas the lexical competition view explains the semantic blocking effect (Belke, Meyer et al., 2005; Damian et al., 2001; Howard et al., 2006; Kroll & Stewart, 1994), the blocking effect remains unexplained under the response exclusion account. In a semantic blocking experiment, there are no distractor words that activate an articulatory program during the planning of the picture name. As no articulatory program for a distractor word needs to be removed from the output buffer, semantic interference should not occur. Thus, the strong correlation between the size of the interference effects and the slopes of the delta plots in both the picture-word interference task and the semantic blocking task suggests that selective inhibition may be exerted in similar ways in the two tasks. This would imply that the semantic interference effect in the picture-word interference paradigm arises during lexical selection rather than the exclusion of the articulatory program of the distractor from an output buffer.

Conclusions

The main goal of the present study was to determine whether selective inhibition would be involved in a task where speakers did not have to suppress a response to a single salient distractor, as is the case in the picture word interference task. The results of the semantic blocking experiment clearly support this hypothesis.

Thus, selective inhibition is invoked not only when speakers have to suppress their reactions to a single distractor, but also when strong competition arises between conceptual and/or lexical units for other reasons, for instance due to the prior experience in an experiment.

Appendix

List of target names of pictures used in semantic blocking task. The English translations are given in parentheses.

ANIMALS: eend (duck), muis (mouse), slang (snake), vis (fish).

FURNITURE: bed (bed), kast (wardrobe), lamp (lamp), stoel (chair).

TOOLS: boor (drill), hark (rake), tang (pliers), zaag (saw).

BODYPARTS: arm (arm), neus (nose), oor (ear), voet (foot).

Chapter 5: Predicting Naming Latencies for Action Pictures: Dutch Norms

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This chapter is an adapted version of: Shao, Z., Roelofs, A., & Meyer, A. S. (2013). Predicting naming latencies for action pictures: Dutch Norms. *Behavior Research Methods,* Advance online publication. doi:10.3758/s13428-013-0358-6.

CHAPTER 5 PREDICTING ACTION NAMING IN DUTCH

Abstract

The present study provides Dutch norms for age of acquisition, familiarity, imageability, image agreement, visual complexity, word frequency, and word length (in syllables) for 100 line drawings of actions taken from Druks and Masterson (2000) and 24 additional drawings. Ratings were provided by 117 Dutch participants. Word frequency was determined on the basis of the SUBTLEX-NL corpus (Keuleers, Brysbaert, & New, 2010). For 104 of the pictures, naming latencies and name agreement were determined in a separate naming experiment with 74 native speakers of Dutch. The Dutch norms closely correspond to the norms for British English. Multiple regression analyses showed that age of acquisition, imageability, image agreement, visual complexity and name agreement were significant predictors of the naming latencies, whereas word frequency and word length were not. Combined with the results of a principal component analysis, these findings suggest that variables influencing the processes of conceptual preparation and lexical selection make the largest contribution to the action naming latencies.

CHAPTER 5 PREDICTING ACTION NAMING IN DUTCH

Introduction

The picture naming task is a well-established research tool for studying word production. In this task, participants are required to name a set of pictures as quickly and accurately as possible. There are a number of different models of the cognitive processes leading from the perception of a picture to the articulation of its name. The models differ in many ways, but they all agree that picture naming involves four main processing steps, namely (i) perceptual and conceptual identification of the depicted object or event, hereafter *conceptual preparation*, (ii) selection of a suitable name for the object or event, hereafter *lexical selection*, (iii) encoding of the corresponding word form (i.e., encoding morphological, phonological, and phonetic representations), hereafter *word-form encoding*, and (iv) articulation (e.g., Caramazza, 1997; Glaser, 1992; Humphreys, Riddoch, & Quinlan, 1988; Levelt, Roelofs, & Meyer, 1999, Rapp & Goldrick, 2000; Roelofs, 1992).

For many applications of the picture naming task, it is useful to know beforehand which picture names speakers are likely to choose and how difficult the naming task will be. This is, for instance, the case when sets of pictures are split to be presented to different groups of speakers or for testing at different occasions, or when pictures are needed that speakers are likely to find easy or difficult to name. Following Snodgrass and Vanderwart's (1980) seminal study, norms have been developed for various sets of pictures and for different languages. These norms often include not only the preferred picture names and the corresponding naming latencies, but also indicators of various properties of the pictures and their names, including, for instance, their visual complexity, the age of acquisition of the dominant name, and the frequency of the name. Comparisons of these data sets have shown that the norms are, to some extent, specific to the language tested. For instance, Van Schagen and colleagues (1983) found no significant correlation for name agreement or familiarity between their Dutch norms for object pictures and the English norms for the same picture set provided by Snodgrass and Vanderwart (1980).

Most norming studies have concerned pictures of objects (e.g., Snodgrass & Vanderwart, 1980 for English; Sanfeliu & Fernandez, 1996 for Spanish; Alario & Ferrand, 1999 for French; Nisi, Longoni, & Snodgrass, 2000 for Italian; Wang, 1997 for Chinese; Severens, Lommel, Ratinckx, & Hartsuiker, 2005 for Dutch). Yet, norms for action pictures are needed in many research, educational, and clinical contexts, for instance when verb or action specific knowledge or the underlying cortical representations are to be investigated, or when morphologically complex forms, such as past tense forms of verbs, are to be elicited (e.g., Gentner, 1981; Kemmerer & Tranel, 2000).

Norms for action pictures have been provided for some languages, including English (e.g., Druks & Masterson, 2000; Szekely et al., 2005), French (Schwitter, Boyer, Meot, Bonin, & Laganaro, 2004) and Spanish (Cuetos & Alija, 2003), but, to the best of our knowledge, not for Dutch. The present study fills this gap by providing Dutch norms for a set of line drawings of actions, one hundred drawings from the set used in the English naming battery (Druks & Masterson, 2000, D & M hereafter) and 24 additional drawings (Konopka & Meyer, 2012).

The present study was carried out in two steps: The first step was an online study, where participants rated the action pictures on a number of scales described below. We largely followed D & M in choosing the rating scales and preparing the materials, and we determined how well the ratings of the drawings given by English and Dutch participants correlated with each other. The second step was a laboratory study, where participants named the pictures as quickly and accurately as possible.

We determined name agreement and the average naming latency for each picture. Subsequently, we determined how well each of the variables assessed in the rating study as well as name agreement and indicators of the length and frequency of the picture names predicted the naming latencies. Since D & M did not record naming latencies, such analyses could not be carried out for the English data.

In the rating study the participants were asked to rate two properties of the drawings, namely their visual complexity, defined as the amount of detail in the drawings, and image agreement, defined as the degree to which the visual image evoked by the picture name corresponded to the drawing. Visual complexity probably affects the ease of recognizing the actions, and we therefore expected the picture naming latencies to increase with the complexity of the pictures (see also Atteneave, 1957; Ellis & Morrison, 1998; but see Snodgrass & Yuditsky, 1996). Image agreement should also affect object recognition, with poor imagine agreement leading to slow object recognition and hence long object naming latencies (e.g., Barry, Morrison, & Ellis, 1997).

Three further rating scales, of imageability, familiarity, and subjective age of acquisition, concerned the dominant names of the actions. Imageability refers to the degree to which a word can evoke mental images. It can be used to index semantic richness and to study the activation of semantic codes during lexical processing (e.g., Cortese, Simpson, & Woolsey, 1997). Familiarity indicates the subjective frequency of exposure to a word. Several studies have shown that familiar written words are produced and recognized faster than less familiar ones (e.g., Balota, Pilotti, & Cortese, 2001; Connine, Mullennis, Shernoff, & Yelen, 1990). We expected negative correlations of imageability and familiarity with the action naming latencies.

Age of acquisition (AoA hereafter) refers to the age at which words are learned. It can be measured through estimates given by adults, or by more objective measures (e.g., parental or teacher's ratings or formal tests) of when children can name pictures or read words. Several studies have shown that subjective ratings of AoA and objective measures correlate well (e.g., Carroll & White, 1973; Gilhooly & Gilhooly, 1980; Lyons, Teer, & Rubenstein, 1978; Morrison, Chappell, & Ellis, 1997; Walley & Metsala, 1992). In the present study, ratings were obtained, as in D & M’s study. There is a large body of research demonstrating the strong impact of AoA in a variety of linguistic tasks (e.g., Brysbaert & Cortese, 2011; see Barry et al., 1997 for a review). It has been shown that naming latencies increase with age of acquisition in both object (e.g., Carrol & White, 1973; Ellis & Morrison, 1998), and action naming (e.g., Bogka et al., 2003; Bonin, Boyer, Méot, Fayol, & Droit, 2004; Morrison, Hirsh, & Duggan, 2003). The precise origin of the AoA effect in picture naming is still under debate (see Johnston & Barry, 2006 for a review). But there is some consensus that early learned concepts benefit a processing advantage over late-learned concepts during the naming process, either at relatively early stage, i.e., during conceptual preparation or lexical selection (e.g., Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Catling & Johnston, 2006), or at a relatively late stage, i.e., during word-form encoding (Brown & Watson, 1987). We expected to see a positive correlation of AoA with the picture naming latencies.

In addition to the above ratings, we included estimates of the frequencies of the action names in the language (using the SUBTLEX Dutch database; Keuleers, Brysbaert, & New, 2010) and their length (in terms of number of syllables) as predictors of the naming latencies. There is a large literature demonstrating the impact of frequency on the performance in word and picture naming (e.g., Barry et al., 1997;

Cuetos, Ellis, & Alvarez, 1999; Ellis & Morrison, 1998; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Knobel, Finkbeiner, & Caramazza, 2008; Lachman, Shaffer, & Hennrikus, 1974; Snodgrass & Yuditsky, 1996). There has been some debate in the literature about the origin of the frequency effect in picture naming, but overall the consensus is now that frequency affects both lexical selection and word-form encoding (see Jescheniak & Levelt, 1994; Piai, Roelofs, & Van der Meij, 2012; Strijkers, Costa, & Thierry, 2010).

Several studies have shown that long words take longer to initiate than shorter words (e.g., Eriksen, Pollack, & Montague, 1970; see Ferrand & Segui, 2003; Henderson, 1982, for reviews), most likely because speakers generate the phonological and phonetic codes of successive syllables in sequence during word-form encoding (e.g., Meyer, Belke, Häcker, & Mortensen, 2007; Roelofs, 2002). However, speakers can initiate the articulation of a word on the basis of a partial form representation (e.g., the representation of one syllable), in which case no word length effect is found. Thus, whether or not a word length effect is obtained may depend on the speakers' response strategy (Damian, Bowers, Stadthagen-Gonzalez, & Spalek, 2010; Meyer, Roelofs, & Levelt, 2003).

From the naming study, we obtained indicators of name agreement for the pictures, which is the extent to which participants agree on the name of one picture. Name agreement is a robust predictor of naming difficulty. In many studies, pictures with a single dominant name have been found to be named more quickly than pictures with multiple plausible names (Barry et al., 1997; Lachman et al., 1974; Paivio, Clark, Digdon, & Bons, 1989; Vitkovitch & Tyrrell, 1995). The origin of the name agreement effect is not entirely clear. Some evidence suggests that the effect arises during lexical selection. For instance, Johnson and colleagues (1996) found that name agreement affected naming latencies but not object identification decision latencies for the same object pictures. Alario et al. (2004; see also Alario & Ferrand, 1999) proposed that the effect of name agreement reflects how strong the connections are between the pictured object and its possible names, and that competition among the multiple lexical candidates causes a delay in selecting target lexical representations.

In natural languages, many properties of objects and their names are related. For instance, early acquired names will typically be short and frequent and will refer to familiar concepts (e.g., Brown & Watson, 1987; Severens et al., 2005). Consequently, we expected to see inter-correlations between the predictors of naming latencies. We used multiple regression to determine how well each variable independently predicted the naming latencies, and we used principle component analysis to explore which predictors clustered together.

To summarize, the present study provides Dutch norms for action naming. We report naming latencies and indices of name agreement to characterize the overall difficulty of naming each item. In addition, we provide a range of often used measures that characterize the ease of specific aspects of conceptual preparation (including object recognition), lexical selection, and word-form encoding, and report their impact on the naming latencies.

Method

Participants

One hundred and seventeen native Dutch speakers (twenty males, *Mean age* = 28.57 years, range: 16 to 67 years) participated in the online norming study, and seventy-four native Dutch speakers (six males, *Mean age* = 35.23 years, range: 16 to 63 years) participated in the picture naming task[7]. They were selected from the

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[7] Because the same set of pictures were used in both the norming study and the naming task, we used independent participant samples in collecting data for the norming and naming studies.

participant pool of the Max Planck Institute for Psycholinguistics, Nijmegen, the Netherlands. They completed a consent form before the study and were paid for their participation. All participants had normal or correct-to-normal vision.

Norming Scales

Materials. 124 black-and-white line-drawings of actions were used in the normative study. 100 drawings were selected from the corpus provided by Druks and Masterson (2000) and 24 were selected from Konopka and Meyer (2012). In a pilot study carried out with 10 native speakers of Dutch we established the dominant names of the pictures. The rating scales for image agreement and visual complexity were presented in combination with action pictures, whereas the scales for imageability, image agreement, subjective age of acquisition and familiarity were presented with the corresponding written verbs.

All pictures were sized to fit into frames of 150 by 150 pixels on the computer screen. Words were presented in black color in lowercase Tahoma with large font size. The rating scales were presented below the stimuli. The study was programmed using the Oracle Application Development Framework 11.1.1.4.0.

Design and procedure. All participants rated all items on each of the five scales. They rated all items on one scale before moving on to the next scale. The order of the scales was: (i) imageability, (ii) image agreement, (iii) familiarity, (iv) subjective age of acquisition, and (v) visual complexity. The order of the pictures was fixed for each scale and all participants.

On each trial of the image agreement rating task, a verb was presented in the center of a computer screen for one second and followed by the corresponding picture, which remained in view until the participant responded. In the remaining tasks, a single item (a picture or word) was presented per trial until the participant responded. All tasks were self-paced, but the program automatically terminated if no response was recorded within one hour. Participants could not revise their ratings.

Seven-point rating scales were used for all variables except for age of acquisition. In the *imageability* rating task (adapted from Paivio, Yuille, & Madigan, 1968) participants were presented with written verbs and instructed to rate how readily each verb evoked mental images. A value of 1 on the scale indicated the lowest level imageability and a value of 7 indicated the highest level of imageability.

In the *image agreement* rating task (adapted from Snodgrass & Vanderwart, 1980), participants were instructed to rate how closely each picture resembled their mental images of the action. The value of 1 indicated that the picture provided a very poor match, and the value of 7 indicated a very good match to the participant's mental image of the action.

In the *familiarity* rating task (adapted from Gilhooly & Logie, 1981), participants were required to rate the familiarity of each word as to the number of times that had experienced it. The value of 1 indicated that the participant had *never* seen, heard or used the word and the level of 7 indicated that they saw, heard, or used the word *nearly every day*.

In the *age of acquisition* rating task (adapted from Carroll & White, 1973), participants were instructed to rate on a 9-point scale the age at which they thought they had acquired the verb. In the scale, 1 indicated 0 - 2 years, 2 indicated 3 years, 3 indicated 4 years, 4 indicated 5 years, 5 indicated 6 years, 6 indicated 7-8 years, 7 indicated 9-10 years, 8 indicated 11–12 years, and 9 indicated 13 years and older. If the participants did not know the meaning of a verb, they should choose "Ik ken het woord niet (I don't know the word)". "Learning a verb" was defined as the age at which the participants thought they would have understood the verb if somebody had used it in front of them even if they did not yet say, read, or write the verb.

In the *visual complexity* rating task (adapted from Snodgrass & Vanderwart, 1980), participants were instructed to rate the complexity of each picture. The value of 1 indicated that the picture was very simple, and the value of 7 indicated it was very complex. Participants were required to rate the complexity of the drawing itself rather than the complexity of the action it represented. Here, "complexity" was identified as the amount of details or intricacy of lines in the picture.

Picture Naming Task

Materials. 20 items were excluded from the set because the online study showed that their dominant names were compound words in Dutch (e.g., SKIP corresponded to *touwtje springen*), or the pictures turned out to have no specific name in Dutch (e.g., no existing single Dutch word corresponded to HATCH). The remaining 104 pictures were resized to fit into frames of 4 by 4 cm on the computer screen (2.29° of visual angle).

Procedure. On each trial, a fixation cross (+) was presented first for 800 ms in the center of the screen. Then a picture was shown for 600 ms, followed by a red flashing exclamation mark, which was presented until the end of the trial (see also Chapter 2 for details). The exclamation mark was used to remind participants to respond quickly. The trial was terminated as soon as the voice key was triggered or, if the participant did not respond, 2000 ms after the onset of the picture. The inter-stimulus interval was 1500 ms. The order of items was random and different for each participant. The participants were tested individually.

Apparatus and data analyses. The naming task was controlled by a HP 8540P laptop with the software package Presentation® (Version 14.3, www.neurobs.com). Naming latencies were recorded online using a voicekey and were later confirmed or corrected using the speech analysis program Praat (Boersma, 2001). Responses were coded as errors when participants used names that were different from the dominant names, or when the response contained a repair or disfluency (stutters or starting with filler words).

Scoring. The participants' responses were transcribed to determine name agreement. We computed two indicators of name agreement. The first was the proportion of participants who used the dominant name determined in the pilot study. This proportion represents the degree of agreement on a name but does not reveal how many different names the participants used. Information about the spread of responses was captured in a second indicator, the *H*-statistic, introduced by Snodgrass and Vanderwart (1980). In formula (1) below, *k* represents the number of different names given to each picture, *i* represents the number of names assigned to one picture, and P_i represents the proportions of each assigned name.

(1) $$H = \sum_{i=1}^{k} P_i \log_2(1/P_i)$$

If there is only one name for a picture, *H* is zero. If there are two names with equal frequency, *H* is 1. *H* increases with the number of responses given, and generally decreases with the proportions for each response.

Results

Table 1 provides descriptive statistics for each of the variables assessed in the rating study, along with word frequency and word length (i.e., number of syllables) of the dominant names. Because of technical problems, five participants could not provide ratings of AoA, imageability and image agreement. The ratings for each item are listed in Appendix A. The ratings show that the action pictures, though depicted in line drawings, have high imageability, good image agreement, and low visual complexity.

Table 1
Descriptive Statistics for 124 Dutch Action Pictures for Age of Acquisition (AoA), Familiarity, Imageability, Image Agreement, Visual Complexity, Word Frequency, and Word Length. SD = Standard Deviation

	AoA	Familiarity	Image-ability	Image agreement	Visual complexity	Word frequency	Word length
Mean	5.03	4.54	5.80	6.08	3.49	1.41	2.18
SD	1.23	1.01	.48	.68	.89	.71	.44
Median	5.00	4.43	5.91	6.33	3.45	1.42	2.00
Range	1-9	1-7	1-7	1-7	1-7	0-3.11	2-4

Table 2
Descriptive Data for H-Statistic, Proportion of Dominant Names, Naming Latency (in Milliseconds), and Error Rate. SD = Standard Deviation

	H-Statistic	Proportion of dominant names	Naming latency	Naming error rate (%)
Mean	.32	0.86	886	23
SD	.53	0.14	135	20
Range	0-3.09	0.45-1.00	446-2331	0-82

Table 3

Matrix of Correlations between Naming Latencies and the Predictor Variables

	AoA	Familiarity	Image-ability	Image agreement	Name agreement	*H*-statistic	Word length	Visual complexity	Word frequency
Naming latency	.43**	-.39**	-.57**	-.38**	-.53**	.43**	.27**	.36**	-.24*
AoA		-.64**	-.36**	.14	-.29**	.21*	.35**	.31**	-.55**
Concept familiarity			.49**	-.03	.21*	-.11	-.22*	-.20*	.61**
Imageability				.26**	.27**	-.27*	-.13	-.20*	.10
Image agreement					.27**	-.14	.04	-.11	-.15
Name agreement						-.71**	-.12	-.11	.12
H-statistic							.06	.12	-.07
Word length								-.05	-.26**
Visual complexity									-.21*

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

Table 4

Results of Multiple Regression Analysis with Naming Latency as Criterion Variable and Age of Acquisition (AoA), Familiarity, Imageability, Image Agreement, Visual Complexity, Word Frequency, Word Length, and H-Statistic as Predictor Variables. Only Variables that Made a Significant Contribution Are Listed in the Table. SE = Standard Error

Variable	Beta	SE	*t*-Value
AoA	.25	8.67	3.12**
Imageability	-.32	21.54	- 4.15**
Image agreement	-.29	14.42	- 3.95**
H-statistic	.24	18.10	3.31**
Visual complexity	.16	10.98	2.22*

Note: ** $p < .01$. * $p < .05$. $N = 102$.

Table 2 provides descriptive statistics about name agreement (represented by both proportion of dominant names and *H*-statistic), naming latencies and response error rates. The corresponding values for each picture are listed in Appendix B. The mean naming latencies were based only on responses using the dominant names. Any stuttered and repaired response was excluded from the following analysis.

Table 3 shows the correlations among all variables. All of the average ratings as well the indicators of name agreement, word frequency and length (i.e., syllable number) showed the expected correlations with the object naming latencies. As can be seen, the two variables specifically pertaining to word-form encoding (i.e., word frequency and word length) showed the weakest correlations with the naming latencies, and the variables pertaining to name agreement showed the highest correlation with the latencies. The table also shows that, as predicted, some of the ratings were strongly correlated: Familiarity correlated with imageability, AoA, and name frequency; the latter two variables were also correlated strongly with each other; and, unsurprisingly, the two indicators of name agreement were highly correlated.

Stepwise multiple regression was used to assess how much of the variance in the naming latencies was explained uniquely by each of the predictor variables. Since both the *H*-statistic and the proportion of dominant names were used to indicate name agreement, only the *H*-statistic was included in the analyses. A similar pattern was found when replacing the *H*-statistic with the proportion of dominant names.

The results, summarized in Table 4, show that the *H*-statistic, image agreement, imageability, visual complexity, and AoA were significant predictors of naming latencies. The regression analysis yielded $R^2 = .55$, $F(6, 94) = 24.37$, $p < .001$.

A principal component analysis (PCA) was used to explore how many underlying factors were reflected by the predictors. The PCA with varimax rotation was computed on all 8 original variables for a sample of 104 Dutch verbs. The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis, $KMO = .68$. Bartlett's test of sphericity, $\chi^2(28) = 212.96$, $p < .001$, indicated that correlations between variables were sufficiently large for PCA. Three components had eigen-values bigger than 1 over the Kaiser's criterion and in combination explained 67.51% of the variance. Table 5 shows the factor loadings after rotation. Three factors were extracted. In detail, Factor 1 loaded on AoA, familiarity, and word frequency; Factor 2 loaded on imageability, image agreement, and name agreement; and Factor 3 loaded on name length and visual complexity. Similar results have been obtained by Bonin et al. (2004), who found one factor loading on AoA, familiarity, and visual complexity, and another factor loading on imageability, image agreement, and name agreement. However, different from the study of Bonin et al., we found that visual complexity grouped with name length (forming a third factor) rather than AoA and familiarity (our first factor).

Table 5
Summary of Results of the Principal Component Analysis

Variable	Rotated Factor Loading Factor 1	Factor 2	Factor 3
AoA	.33		
Familiarity	-.31		
Word frequency	-.35		
Image agreement		.48	
Imageability		.38	
H-statistic		-.44	
Word length			.68
Visual complexity			-.70
Eigenvalue	2.82	1.56	1.02
% Variance	35.25	19.49	12.77

As noted, the majority of the pictures used in the present study were taken from the corpus provided by Druks and Masterson (2000)[8]. Table 6 shows the descriptive statistics for the items included in both studies, as well as the results of *t*-tests comparing the average ratings from the two language and the correlations among the ratings. The averages were significantly different for all variables except AoA. Ratings of AoA were switched back to the real age by using the midpoint of the ranges. Compared with the British-English speakers of M & D, Dutch speakers thought the pictures were visually less complex, $t(88) = 14.64$, $p < .01$, the words were more familiar, $t(88) = 5.67$, $p < .01$, and harder to imagine, $t(88) = 23.35$, $p < .01$. The Dutch target words were longer than the English equivalents, $t(88) = 1.72$, $p <$

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[8] For the rating of age of acquisition, the English norming used a 7-point scale instead of a 9-point scale.

.05. However, the table also shows that, in spite of these differences in the average ratings, the ratings for the individual items in the two languages were highly correlated. There was only a weak correlation for number of syllable, which is not surprising given that different languages were tested.

Table 6

Comparison and Correlation between Dutch and English Action Normative Data

Variable	Mean/SD	Dutch	English	Correlation
AoA	Mean	5.03 (5-6 years)	2.56 (5-6 years)	.71**
	SD	1.23	.68	
Imageability	Mean	5.85	4.26	.63**
	SD	.48	.58	
Familiarity	Mean	4.54	3.96	.74**
	SD	1.01	1.41	
Word length	Mean	2.18	2.06	.27*
	SD	.44	.23	
Visual complexity	Mean	3.48	4.26	.80**
	SD	.89	0.77	

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

Discussion

The present study is, to the best of our knowledge, the first norming study of action pictures in Dutch. One hundred pictures were selected from D & M's battery and 24 additional pictures from Konopka and Meyer (2012). Ratings of visual complexity, AoA, imageability, image agreement, and familiarity for each item are listed in Appendix A. Appendix B lists the average naming latencies for the dominant name of each item, the total number of alternative names and two indicators of name agreement (i.e., proportion of dominant names and *H*-statistic). These norms should be useful for future studies where, for instance, action drawing are required that are fast or slower to be named, or where sets of pictures are to be constructed that are matched for, say visual complexity or AoA. We found that the ratings of AoA, imageability, familiarity, and visual complexity obtained here correlated well with the ratings in D & M's norming study for British English. Given similarity of the two languages and the similarity of the speakers' cultural and educational background, this is perhaps not too surprising but it does demonstrate the reliability of the ratings.

All predictor variables included in the present study were significantly correlated with the picture naming latencies. Multiple regression analyses showed that only imageability (how easy it is to create a mental image given the action name), image agreement (how well the drawing corresponded to the raters' mental image of the action), the *H*-statistic (indicative of name agreement), age of acquisition, and visual complexity independently predict naming latencies. Taken together, these variables accounted for 55% of the variance in the naming latencies. By contrast, there was no independent contribution of familiarity, word frequency, and word length. Given the likely processing-origins of these effects discussed in the Introduction, these results suggest that the time the speakers needed to produce suitable names for action drawings depends to a large part on the time they require to identify the actions (i.e., conceptual preparation) and to select appropriate lexical units (i.e., lexical selection), and much less on the time they need to retrieve the corresponding morphological and phonological forms (i.e., word-form encoding). Of course, it is important to keep in mind that the pattern seen here may not generalize to other sets of pictures. For instance, how much time speakers need to identify the actions shown, and how variable this time is will depend on the kinds of actions and the quality of the pictures. Similarly, the impact of lexical variables such as word frequency and word length will depend on the range present in the picture set. Nevertheless, the present results suggest that in action naming, differences in the duration of early cognitive processes, related to visual and conceptual processes (i.e., conceptual preparation) and the selection of a suitable name (i.e., lexical selection), contribute more to latency differences than differences in the duration of later word-form encoding processes.

This conclusion is in line with earlier action norming studies in other languages. For instance, Bonin and colleagues (2004; see also Schwier, Boyer, Méot, Bonin, & Laganaro, 2004) found that name agreement, image agreement, and AoA significantly predicted naming latencies in French. Cuetos and Alija (2003) found that AoA and name agreement were significant predictors of action naming latencies in Spanish. Additionally, the absence of a frequency effect in the present study is consistent with other mentioned normative studies (e.g., Bonin et al., 2004; Cuetos & Alija, 2003; Schwier et al., 2004). Apparently name agreement, image agreement, and AoA are relatively stable predictors of action naming latencies across languages.

Studies of object naming have also highlighted the impact of early visual/conceptual variables on naming latencies. Specifically, Alario et al. (2004) showed that more complex drawings took more time to be recognized than the less complex drawings (see also Ellis & Morrison, 1998), and pictures with higher image agreement ratings were named faster than pictures with lower ratings. Moreover, object naming studies also found that the frequency effect disappeared when AoA was controlled for (Bonin, Peereman, Malardier, Méot, & Chalard, 2003; Carroll & White, 1973; but see Barry et al., 1997). These findings suggest a commonality between object and action naming. However, effects of early visual/conceptual variables appear to be less pervasive in object than in action naming. For instance, many studies failed to find effects of visual complexity on object naming latencies (Barry et al., 1997; Bonin, Chalard, Méot, & Fayol, 2002; Bonin et al., 2003; Cuetos et al., 1999; Snodgrass & Yuditsky, 1996). A possible cause for this might be that object pictures are generally easier to process at the recognition and conceptualization level than action pictures. Consistent with this assumption, we found in an earlier object and action naming study (Shao et al., 2012) that inhibitory control was more systematically involved in action naming than object naming, possibly because more interference among competing conceptual representations occurred during conceptual preparation in the action naming task. Overall, higher- level cognitive processes may be more influential determinants of the speed of action than object naming.

Conclusions

To recapitulate, the present study provides Dutch normative data for 124 line drawing actions. Naming latencies for a subset of 104 drawings were also collected. Multiple regression analyses showed that name agreement, image agreement, imageability, visual complexity, and age of acquisition were significant predictors of the naming latencies.

Appendix A

English name	Dominant Dutch name	Visual complexity	Image agreement	Familiarity	Image -ability	AoA (years)
stroke	aaien	3.11	6.11	4.92	6.11	4
stop	aanhouden	4.88	5.33	3.76	4.22	7,8
touch	aanraken	3.39	5.54	4.97	5.61	5
light	aansteken	3.34	6.2	4.32	5.41	6
arrest	arresteren	3.51	6.56	4.08	5.17	7,8
drive	autorijden	3.88	6.67	5.57	6.49	5
beg	bedelen	4.29	6.37	3.54	5.3	7,8
pray	bidden	3.46	6.52	4.43	5.71	6
bite	bijten	4.54	5.82	4.37	5.93	4
bark	blaffen	3.88	6.68	3.88	5.72	4
blow	blazen	2.5	6.36	4.05	5.92	4
bleed	bloeden	3.61	6.02	4.43	6.21	5
beat	boksen	5.09	5.52	3.68	6.07	6
drill	boren	4.54	6.56	3.8	5.7	6
build	bouwen	4.62	5.4	4.67	5.55	4
bowl	bowlen	2.63	6.38	3.46	6.36	7,8
knit	breien	3.44	6.58	3.94	6	6
roar	brullen	4.54	5.88	3.51	4.92	5
bend	bukken	2.31	6.21	4.26	5.76	5
dance	dansen	3.79	6.02	4.98	6.4	4
carry	dragen	2.4	5.9	5.42	5.27	4
float	drijven	2.61	5.05	3.85	5.42	6
drink	drinken	2.35	6.69	6.63	6.59	3
dream	dromen	3.59	6.38	5.33	4.34	5
drip	druppelen	2.13	6.45	3.41	5.31	6
dive	duiken	3.63	5.88	4.1	5.79	6
push	duwen	2.96	5.89	4.54	5.67	5
mop	dweilen	2.89	5.93	4.28	5.94	6
eat	eten	3.21	6.08	6.85	6.69	3
photograph	fotograferen	4.29	6.01	4.79	6.07	6
whistle	fluiten	2.71	6.49	4.03	5.74	5
yawn	gapen	2.39	6.44	4.99	6.02	5
give	geven	4.34	6.02	6.3	5.49	4
slide	glijden	3.81	6.19	3.74	5.32	4
smile	glimlachen	1.96	6.4	5.03	6.37	5
throw	gooien	3.05	6.02	4.76	6	4
dig	graven	4.21	5.98	3.69	5.88	5
rake	harken	2.58	6.61	3.18	5.91	6

cough	hoesten	3.86	5.94	5.28	6.04	4
cry	huilen	2.59	6.61	5.26	6.47	3
pour	inschenken	2.75	6.57	5.15	5.86	6
juggle	jongleren	5.04	6.68	2.77	6.02	7,8
comb	kammen	2.48	6.7	4.83	6.05	4
tickle	kietelen	3.85	4.05	3.88	5.86	4
watch	kijken	3.37	4.84	6.7	5.27	3
climb	klimmen	4.32	4.33	4.18	5.88	5
knock	kloppen	3.12	6.53	4.63	5.53	5
kneel	knielen	2.56	6.15	2.95	5.68	6
pinch	knijpen	2.36	6.05	3.95	5.38	4
cut	knippen	2.48	--	5.25	6.22	4
cook	koken	5.2	6.33	6.52	6.45	5
crawl	kruipen	2.53	6.49	3.56	6.14	4
cross	oversteken	4.16	6.29	4.69	5.69	4
curl	krullen	4.61	5.87	3.94	5.11	6
kiss	kussen	2.39	6.12	5.95	6.49	5
laugh	lachen	2.4	6.38	6.15	6.55	3
drop	laten vallen	2.5	5.8	5.2	5.52	4
lean	leunen	3.51	5.87	3.97	5.29	6
read	lezen	2.82	6.72	6.49	6.36	4
lick	likken	3.72	5.07	4.34	5.99	4
walk	lopen	2.59	5.94	6.64	6.49	3
ring	luiden	2.61	5.62	3.51	4.15	7,8
march	marcheren	5.62	6.59	2.6	5.63	9,10
swat	meppen	3.89	5.51	3.44	5	6
sew	naaien	3.39	6.12	3.78	6	6
sneeze	niezen	3.87	6.31	5.34	6.14	4
open	openen	2.65	4.65	5.5	5.54	5
ride	paardrijden	3.05	6.82	3.5	6.31	6
peel	pellen	4.8	5.66	3.43	5.33	7,8
plant	planten	3.36	6.37	4.56	5.69	5
post	posten	3.64	6.35	4.06	5.01	5
rain	regenen	1.79	6.51	5.76	6.54	4
run	rennen	2.57	6.52	5.51	6.17	4
row	roeien	3.13	6.67	4.03	6.1	6
stir	roeren	2.46	6.56	4.59	5.94	5
smoke	roken	4.04	6.1	5.11	6.4	6
salute	salueren	2.84	6.79	2.44	5.08	9,10
skate	schaatsen	2.84	6.29	3.64	6.32	5

scoop	scheppen	4.63	3.95	3.9	5.09	5
shave	scheren	5.63	6.28	4.82	6.11	6
shoot	schieten	3.54	5.37	4.74	5.86	6
swing	schommelen	3.13	6.88	4.11	6.25	4
kick	schoppen	3.2	5.05	3.84	5.77	4
write	schrijven	3.76	6.46	6.22	6.26	5
ski	skieen	3.66	6.81	3.35	6.35	7,8
sleep	slapen	3.27	6.75	6.72	6.24	3
destroy	slopen	5.67	6.42	3.91	5.18	6
melt	smelten	4.77	4.8	4.06	5.37	6
snow	sneeuwen	5.12	6.47	4.78	6.46	4
play	spelen	4.37	5.88	5.36	5.77	3
jump	springen	3.06	5.12	4.46	6.33	4
sting	steken	3.62	5.18	3.85	5.17	6
vacuum	stofzuigen	3.65	6.64	5.56	6.52	6
iron	strijken	4.6	6.72	4.84	6.38	6
tie	strikken	2.59	6.54	3.61	5.42	5
bounce	stuiteren	3.65	5.81	3.31	5.5	5
surf	surfen	3.94	6.43	3.13	5.86	7,8
brush	tanden poetsen	3.91	6.69	6.27	6.72	4
draw	tekenen	3.93	6.38	5.59	6.21	4
skip	touwtje springen	3	6.87	2.96	6.23	5
pull	trekken	3.8	4.63	5.44	5.4	4
type	typen	4.23	6.11	5.55	6.38	7,8
hatch	uitkomen	3.46	4.92	4.39	3.54	6
squeeze	uitpersen	4.21	5.41	3.45	4.93	6
fall	vallen	3.49	5.3	4.97	5.72	4
catch	vangen	3.1	3.08	5.22	5.48	4
sail	varen	2.77	5.92	3.96	5.96	5
paint	verven	3.18	6.31	4.32	6	5
fish	vissen	4.39	6.65	4.37	6.15	5
fly	vliegen	3.65	5.24	5.25	6.15	5
fold	vouwen	2.71	6.33	3.75	5.63	5
wash	wassen	3.28	5.09	5.86	5.89	4
water	water geven	3.09	6.48	4.94	6.06	5
weigh	wegen	3.04	5.55	4.3	5.26	6
weave	weven	5.11	6.41	2.79	4.6	7,8
rock	wiegen	3.93	6.04	3.15	5.12	6
point	wijzen	1.93	6.73	4.6	5.63	4

sing	zingen	2.57	6.42	5.76	6.13	4
sink	zinken	4.28	6.47	3.2	5.05	6
sit	zitten	2.65	6.63	6.38	6.25	3
wave	zwaaien	4.76	6.53	4.69	6.33	4
swim	zwemmen	4.15	6.57	4.6	6.49	4
sweat	zweten	2.89	6.1	5.01	5.81	6

Appendix B

Picture name	Number of names	Proportion of dominant names	*H*-statistic	Mean RT (ms)
arrest	1	1.00	0.00	1120
bark	2	0.98	0.17	856
beg	3	0.88	0.64	1080
bite	2	0.98	0.15	815
bleed	3	0.95	0.35	971
blow	2	0.93	0.36	804
bounce	6	0.72	1.35	935
bowl	4	0.50	1.32	918
build	4	0.83	0.92	848
carry	6	0.70	1.43	861
catch	3	0.77	0.92	908
climb	4	0.88	0.69	970
comb	3	0.97	0.20	700
cook	2	0.93	0.36	788
crawl	1	1.00	0.00	747
cross	4	0.80	0.97	846
cry	1	1.00	0.00	744
curl	4	0.67	1.24	1056
cut	1	1.00	0.00	801
dance	1	1.00	0.00	745
destroy	8	0.68	1.67	1193
dig	7	0.55	1.79	942
dive	3	0.87	0.87	840
draw	2	0.95	0.27	976
dream	5	0.75	1.06	1040
drill	1	1.00	0.00	783
drink	2	0.98	0.16	715
drip	2	0.98	0.17	857
eat	1	1.00	0.00	785
fish	2	0.98	0.12	866
float	5	0.77	1.17	968
fly	1	1.00	0.00	823
fold	3	0.86	0.64	860
give	3	0.85	0.71	929
iron	1	1.00	0.00	719
juggle	4	0.64	1.33	1059

jump	2	0.99	0.10	750
kick	4	0.95	0.38	794
kiss	2	0.46	1.00	780
kneel	3	0.64	1.23	955
knit	3	0.84	0.74	967
knock	1	1.00	0.00	773
laugh	2	0.97	0.17	671
lean	5	0.78	1.03	902
lick	1	1.00	0.00	843
light	3	0.72	0.96	898
march	3	0.81	0.82	986
melt	9	0.78	1.38	997
open	8	0.60	1.88	899
photograph	3	0.65	1.10	1074
pinch	2	0.97	0.20	960
plant	3	0.96	0.29	893
play	6	0.82	0.93	899
point	2	0.97	0.18	711
post	4	0.95	0.37	1086
pray	2	0.98	0.15	762
pull	6	0.77	1.27	1112
push	1	1.00	0.00	784
rain	2	0.99	0.10	765
rake	3	0.93	0.44	821
read	1	1.00	0.00	681
ride	2	0.70	0.88	879
roar	5	0.81	1.04	896
rock	3	0.84	0.76	1037
row	2	0.82	0.68	796
run	4	0.88	0.71	772
sail	3	0.56	1.07	849
salute	4	0.81	0.97	953
scoop	6	0.54	1.87	1315
sew	1	1.00	0.00	995
shave	5	0.56	1.58	896
shoot	1	1.00	0.00	798
sing	2	0.95	0.29	739
sink	3	0.97	0.20	774

sit	2	0.97	0.17	710
skate	5	0.82	0.93	874
ski	1	1.00	0.00	843
sleep	1	1.00	0.00	693
slide	3	0.95	0.31	729
smile	3	0.63	1.24	1002
smoke	1	1.00	0.00	943
sneeze	4	0.90	0.59	798
snow	1	1.00	0.00	879
sting	5	0.45	1.85	1320
stir	3	0.97	0.20	786
stroke	2	0.97	0.17	943
surf	4	0.92	0.50	927
sweat	4	0.90	0.62	910
swim	1	1.00	0.00	664
swing	3	0.97	0.21	687
throw	5	0.90	0.64	955
tickle	3	0.94	0.37	1176
tie	6	0.90	0.67	1024
touch	4	0.60	1.49	801
type	2	0.99	0.10	768
vacuum	3	0.95	0.33	788
walk	2	0.86	0.58	767
wash	3	0.96	0.30	838
wave	3	0.93	0.40	752
weave	4	0.90	0.64	1009
weigh	3	0.97	0.23	887
whistle	4	0.80	0.98	809
write	2	0.94	0.34	824
yawn	4	0.79	1.00	835

Chapter 6: Electrophysiological evidence that inhibition supports lexical selection in picture naming

This chapter is an adapted version of: Shao, Z., Roelofs, A., Acheson, D. J., & Meyer, A. S. (submitted). *Electrophysiological evidence that inhibition supports lexical selection in picture naming.*

CHAPTER 6 INHIBITION SUPPORTS LEXICAL SELECTION

Abstract

Lexical selection has been proposed to be a competitive process that involves top-down inhibition to suppress activation of competing responses. The present study aimed to investigate the neural mechanisms underlying inhibitory control in lexical selection. Participants were asked to overtly name objects and actions while response times (RTs) and event-related brain potentials (ERPs) were recorded. The difficulty of lexical selection was manipulated by using pictures with high versus low name agreement. Pictures with low name agreement, compared to those with high name agreement, are associated with more alternative responses to the target response. Therefore, we predicted that more inhibition would be required for naming in the low name agreement than in the high name agreement condition. To assess the amount of inhibition, we examined the N2, a negative-going ERP component with a fronto-central scalp distribution that peaks between 200 and 300 ms after a stimulus. Behavioral results showed a main effect of name agreement: RTs were shorter in the high name agreement than in the low name agreement condition for both object and action naming. ERP results showed a larger N2 amplitude in the low relative to the high name agreement condition for both object and action naming. These results suggest that inhibition is engaged to reduce competition during lexical selection in picture naming.

CHAPTER 6 INHIBITION SUPPORTS LEXICAL SELECTION

Introduction

Inhibition of behaviour is often necessary in daily life. The notion of inhibition refers to a wide variety of functions, such as suppression of inappropriate responses or decreasing activation levels (e.g., Kok, 1999). Inhibition has been extensively studied outside of language. There are many non-linguistic tasks that are taken to measure inhibition ability, such as the stop-signal task (Logan, 1994), the antisaccade task (Hallett, 1978), and the Stroop task (Stroop, 1935). Several studies have shown that inhibition is also engaged in language processing. For example, bilingual speakers have been shown to use inhibition to suppress the irrelevant language (e.g., Guo, Liu, Misra, & Kroll, 2011; Misra, Guo, Bobb, & Kroll, 2012; Jackson, Swainson, Cunnington, & Jackson, 2001; Roelofs, Piai, & Garrido Rodriguez, 2011). There is also evidence suggesting that inhibition deficits contribute to the impaired speech production of children with specific language impairment (SLI; e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Seiger-Gardner & Schwartz, 2008; Spaulding, 2010). Moreover, several recent studies indicate the engagement of inhibition during object naming by monolingual adults (e.g., de Zubicaray et al., 2001; de Zubicaray, McMahon, Eastburn, & Wilson, 2002; de Zubicaray, McMahon, Eastburn, & Pringle, 2006; Shao, Roelofs, & Meyer, 2012, Chapter 2; Shao, Meyer, & Roelofs, 2013, Chapter 3).

During speech production, speakers must select lexical representations from the mental lexicon. In this process, several lexical candidates may become simultaneously activated, and the speakers must select the most appropriate one among them. Several models of lexical access propose that lexical selection is competitive so that the selection of a target is hindered by co-activation of competitors (e.g., Abdel Rahman & Melinger, 2009; Bloem & La Heij, 2003; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992; Starreveld & La Heij, 1996). In such models, inhibition may be applied to resolve the competition, thus supporting lexical selection. Other models propose that lexical selection is not competitive, and that a target is selected as soon as a threshold of activation is reached (see Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). In such models, there is no obvious role for inhibition during lexical selection.

Assuming that competition might arise during lexical selection, the present study investigated the contribution of inhibitory control in resolving lexical competition. Participants carried out a picture naming task while their naming response times (RTs) and event-related brain potentials (ERPs) were recorded. The amount of competition arising during lexical selection was manipulated by varying the name agreement for the pictures. Name agreement is the extent to which people agree on a name of a picture. For instance, a dog may always be called *dog*, but a couch may sometimes be called *sofa* rather than *couch*, and other objects may be associated with a whole range of names (e.g., a young person may be called a *baby*, *infant*, *toddler*, *child*, or *girl*). Name agreement has consistently been shown to affect picture naming across languages, independent of variables such as frequency and age of acquisition (e.g., Lachman et al., 1974; Vitkovitch & Tyrrell, 1995): Pictures that elicit many different names are named more slowly than pictures with a single dominant name (e.g., Alario & Ferrand, 1999; Barry et al., 1997; Snodgrass & Yuditsky, 1996; Vitkovitch & Tyrrell, 1995). In Shao et al. (2013, Chapter 4) we showed that this was true for both object and action naming.

As Vitkovitch and Tyrell (1995, also see Cheng, Schafer, & Akyürek, 2010) have pointed out, low name agreement can be caused in three different way: First, speakers may use multiple names to refer to the same object (e.g., *sweater*, *pullover*, *jersey*, *sweatshirt*); second, they may use abbreviations or full forms (e.g., *phone* or *telephone*); and third, they may misidentify objects (e.g., calling a line drawing of celery *rhubarb*, *Chinese leaves*, *cabbage*, or *marrow*). The present study concerned name agreement effects of the first type, which arise because multiple co-activated competitors hinder the selection of target (e.g., Johnson, Pavio, & Clark, 1996). To minimize the likelihood of picture misidentification and the use of abbreviations, we asked participants to familiarize themselves with the pictures and the dominant names before the experiment.

We expected that pictures with low name agreement should be named more slowly than pictures with high name agreement because there is stronger competition during lexical selection when there are several competing names. We surmised that inhibition might be involved during the resolution of the competition. The present study used two ways to assess this assumption, namely through analyses of the participants' RTs, and through analyses of the ERPs to the pictures.

In addition to the participants' RTs, we recorded ERPs to the pictures, aiming to obtain additional evidence about the involvement of inhibition in lexical selection from the assessment of early ERP components. ERP recording during picture naming has been used in several studies, often using silent/mouthed naming to reduce speech motor artifacts (e.g., Brooker & Donald, 1980; Cheng et al., 2010; Greenham, Stelmack, & Campbell, 2000; Wohlert, 1993). However, we were particularly interested in processes occurring well before speech onset, which are unlikely to be strongly affected by such artifacts (e.g., Christoffels, Firk, & Schiller, 2007 for a review; Costa, Strijkers, Martin, & Thierry, 2009; Ganushchak, Christoffels, & Schiller, 2011; Verhoef, Roelofs, & Chwilla, 2009). Therefore, overt naming was used.

Based on a meta-analysis of a large number of studies, Indefrey (2011; Indefrey & Levelt, 2004; see also Costa et al., 2009) estimated the average duration of the main steps involved in picture to be as follows: 0 – 200 ms for the visual and conceptual processes leading to the identification of the picture, 200 – 275 ms for lexical selection, 275– 335 ms for the retrieval of phonological code, 335 – 455 ms for syllabification, and 455 – 600 ms for phonetic encoding, followed by articulation.

In response to visual stimuli, a sequence of ERP components, i.e., P1, N1, P2, and N2 can be seen. This holds not only for picture naming tasks, but also when participants carry out non-linguistic tasks in reaction to visual stimuli. Recent evidence from studies using non-linguistic tasks suggests that the N2 component is associated with inhibition. The N2 is a negative-going deflection with a fronto-central scalp distribution that occurs between 200 – 300 ms after a stimulus. For instance, in the Go/No-Go task, a larger N2 was found on no-go trials, where the response must be stopped, than on go trials, suggesting that the N2 reflects the successful inhibition of the response (e.g., Bruin, Wijers, & Van Staveren, 2001; Carriero, Zalla, Budai, & Battaglini, 2007; Dong, Yang, Hu, & Jiang, 2009; Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 1999; Kok, 1986; but see Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Yeung, Botvinick, & Cohen, 2004 for a different view; see Folstein & Van Petten, 2008 for a review). Although the N2 component is more pronounced in go/no-go tasks in which nonselective inhibition is likely involved, it is also found in the Flanker task (e.g., Heil et al., 2000) or the Stroop task (e.g., Silton et al., 2010) in which selective inhibition may be involved. Thus, the N2 component might be associated with both nonselective and selective inhibition.

Modulations of the N2 have also been found in psycholinguistic studies. For example, Costa et al. (2009) found that the mean amplitude of the N2 peak was positively correlated with naming latencies. Laganaro and colleagues (2012) found that faster speakers had a more negative N2-N3 on anterior brain regions than slower speakers in a picture naming task. One might speculate that the latency differences were related to the participants' inhibition ability, reflected in the N2 component. Most relevant to the present purposes is a study by Cheng et al. (2010). They asked participants to silently name pictures of objects with high or low name agreement and found that name agreement had an effect on the N2 component, with a larger N2 for pictures with low relative to high name agreement. However, somewhat surprisingly, the N2 effect was confined to parietal clusters and did not have the usual fronto-central distribution. Given the estimate of Indefrey and Levelt (2004; Indefrey, 2011) that lexical selection takes place between about 200 – 275 ms after picture onset, Cheng et al. took the timing of the N2 effect (i.e., peaking 290 ms after picture onset) to suggest that the effect occurred during phonological encoding.

Cheng et al.'s interpretation does not correspond to the assumption that inhibition is engaged during lexical selection. However, this interpretation was based on an estimate from Indefrey and Levelt (2004; Indefrey, 2011) that assumed a mean picture naming RT of 600 ms. Other research suggests, however, that this latency may be shorter than what is typically observed. For example, using a large set of object pictures and testing English participants, Shao et al. (2012a, Chapter 2) obtained mean naming RTs of 794 ms (Experiment 1) and 705 ms (Experiment 2). Given that Cheng et al. used similar participants and stimuli, it is possible that the naming RTs in their experiment were also longer than 600 ms, although this could not be assessed because participants named the pictures silently. Assuming a mean naming RT of, for example, 750 ms and proportionally scaling the estimate of Indefrey and Levelt (2004; Indefrey, 2011) would yield a time interval of 250 – 344 ms post picture onset for lexical selection. This timeframe corresponds to the time window for the N2 of Cheng et al.. Thus, it is unclear whether the N2 effect occurred during phonological encoding or during lexical selection.

In the present study, participants also named pictures with high or low name agreement while EEG was recorded. The study extended the work by Cheng et al. in several ways. First, we minimized name agreement effects due to misidentification of the objects by familiarizing the participants with the pictures before the main experiment. Second, we recorded overt speech latencies rather than using silent speech. This allowed us to exclude incorrect and abnormally fast or slow responses from the analyses. Moreover, it allowed us to rescale the estimates for the word planning stages of Indefrey and Levelt (2004; Indefrey, 2011) based on the observed mean naming RT, giving us an improved estimate of the time interval for different stages of production planning. In this way, we could assess whether the inhibition reflected by the N2 is applied during lexical selection or during phonological encoding, as Cheng et al. (2010) assume. Finally, in continuation of earlier work (Shao et al., 2012; Chapter 2), we used both object and action pictures as stimuli. In the earlier study, we found that the participants' latency in the stop-signal task (indicative of their ability to inhibit planned responses) was positively correlated with naming latencies in both object and action naming. Furthermore, ex-Gaussian analyses showed that the stop-signal RT correlated with the parameter mu, capturing the average naming latencies in action naming, and with tau, capturing the proportion of slow naming latencies in object naming. We concluded that inhibition was more systematically involved in action naming, compared to object naming, because the action pictures were more complex than the object pictures and probably activated a larger number of competing responses. This view would be supported if we found a more pronounced N2 for action than object naming in the present study.

In sum, we predicted (1) shorter naming RTs for pictures with high than with low name agreement, (2) a larger N2 amplitude for pictures with low than with high name agreement, (3) a negative correlation between the participants' name agreement effects for naming RTs and N2 amplitude, (4) an N2 effect for name agreement in the time window for lexical selection, and finally, (5) a higher N2 amplitude for action than object naming.

Method

Participants

Twenty-five university students participated in the study. They were native Dutch speakers, aged from 19 to 26 years (*Mean* = 21.04 years, 8 men). All participants had normal or corrected-to-normal vision. They participated in exchange for payment.

Material. Eighty line-drawings of objects and 80 line-drawings of actions were used as experimental pictures (see Appendix A). Four further pictures were used on practice trials. One hundred and fifty-four of these pictures were adapted from Druks and Masterson (2000) and 10 were used in earlier study by Konopka and Meyer (2012). For each naming task, half of the pictures had higher name agreement and the other half had lower name agreement (for object naming, $F(1, 78) = 112.99$, $p < .001$; for action naming, $F(1, 78) = 170.35$, $p < .001$; see Appendix B for details). The name agreement values were obtained through a norming study (Shao, Roelofs, & Meyer, 2013; Chapter 4). The set of high and low name agreement pictures were matched for word frequency (see Appendix B) using the SUBTLEX-NL corpus (Keuleers, Brysbaert, & New, 2010). All pictures were scaled to fit into frames of 4 cm by 4 cm on the participant's screen (2.29° of visual angle) and were shown on a light gray background in the center of the screen.

Procedure. Participants were tested individually in a dimly illuminated room. They were seated in a relaxed position in front of a screen and were asked to move and blink as little as possible during the experimental trials. Before the beginning of the experiment, the participants were given a booklet showing the pictures and their names. They were asked to familiarize themselves with the materials and to use only the names in the booklet to refer to the pictures. Then they were given a second booklet showing only the pictures and were required to name them. Errors were immediately corrected by the experimenter. Participants were instructed to name the pictures overtly as fast and accurately as possible.

The object and action pictures were shown in separate test blocks, which were separated by breaks. Twelve participants began with the object naming and thirteen with the action naming task. The order of the experimental items within each block was pseudo-randomized, such that consecutive pictures were not semantically or phonologically related. Each item was shown twice in each block. In total, there were 160 experimental trials per participant.

The object and action naming parts of the experiment each started with a practice block, which consisted of four object or action naming trials respectively. On each trial, a fixation cross (+) was presented first for 500 ms in the center of the screen, followed by a picture, which was shown for 600 ms. Then three asterisks (***) were presented for 2000 ms. Then a black screen was presented for 500 ms plus a jitter, set randomly to 350, 500 or 750 ms. Jitter was used to avoid a slow wave evoked by anticipated stimuli (Walter et al., 1964). A trial ended as soon as the voice key was triggered by the participant's verbal response. If the participant did not respond within 2600 ms after picture onset, the trial was terminated automatically. There was a short break after every 20 pictures.

Behavioral data analyses. Responses were categorized as errors when participants used names that were different from those given in the picture booklet or when the response included a repair or disfluency, such as stuttering or a filled pause. Errors were excluded from the subsequent RT and ERP analyses. Naming RTs were recorded online using a voicekey but were later checked, and corrected using the speech analyses program Praat (Boersma, 2001). Trials with RTs shorter than 500 ms were excluded from the statistical analyses to avoid contamination of the EEG signal with articulation artifacts.

EEG recording and pre-analyses. EEG was recorded continuously from 128 active Ag/AgCl electrodes mounted in a cap according to the 10-5 system (Oostenveld & Praamstra, 2001). The signal was amplified by Biosemi Active-Two amplifiers with a lowpass filter at 128 Hz and sampled with a frequency of 512 Hz. Recordings were performed relative to common mode sense (CMS) and driven right leg (DRL) electrodes placed just anterior to the

Fz electrode. Horizontal eye movements were monitored using electrooculography (EOG) electrodes positioned laterally to the left and right eyes. Two reference electrodes were placed at the mastoids.

Epochs of EEG from -200 to 500 ms relative to picture onset were averaged for each participant. The analyses were confined to this epoch because we were specifically interested in the N2 component, which is observed in the epoch. All trials were visually inspected, and epochs contaminated by eye blinking or speech movements were excluded from averaging in BrianVisionAnalyzer (version 2.0). The data were baseline-corrected using a 200 ms pre-stimulus period. Given our prediction that the N2 should be restricted to frontal regions, ERP analyses were performed by averaging the data over four quadrants divided into the crossing of left/right and frontal/posterior electrodes.

Results

Behavioral

The data obtained from four participants were excluded from the analyses because the average number of retained epochs was lower than 40 per naming task. Of the remaining 21 participants, 9 were given the action naming task first, and 12 were given the object naming task first. Trials with naming RTs shorter than 500 ms and errors were excluded from the analysis (3% of the data)[9]. Figure 1 showed the average naming RTs and error rates for object and action pictures with high and low name agreement. As can be seen, pictures with low name agreement had longer naming latencies and higher error rates compared to pictures with high name agreement. Analyses of variance (ANOVA) were conducted with two within participant factors, name agreement (high agreement, low agreement), naming type (action, object), and one between participant factor, order (actions first, objects first), using participants as the random variables (F_1). For the naming RTs, we found a significant main

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[9] Including all corrected trials yielded mean naming RTs of 727 ms in the high name agreement condition and 828 ms in the low name agreement condition.

effect of name agreement, $F_1(1, 19) = 356.45$, $p < .001$, a main effect of naming type, $F_1(1, 19) = 52.37$, $p < .001$, and a significant interaction between name agreement and naming type, $F_1(1, 19) = 11.13$, $p < .01$, but no main effect of order, or any other interactions, *p*s > .1. The interaction between name agreement and naming type arose because the name agreement effect was stronger for object pictures (114 ms) than for action pictures (82 ms), but both were significant, for objects t_1 (20) = 18.21, $p < .001$, and for actions, t_1 (20) = 10.90, $p < .001$. For the error rates, we found a main effect of name agreement, $F_1(1, 19) = 17.66$, $p < .001$, but no main effect of naming type and order, and no interaction, *p*s > .1.

Additionally, ANOVAs were conducted with name agreement and naming types using items (F_2) as random variables. For naming RTs, we found significant main effects of name agreement, F_2 (1, 39) = 104.26, $p < .001$, and naming type, $F_2(1, 39) = 49.17$, $p < .001$, but no interaction between name agreement and naming type, $p > .1$. For the error rates, we only found a main effect of name agreement, $F_2(1, 39) = 9.81$, $p < .01$, but no main effect of naming type and no interaction, *p*s > 1. In sum, we found a strong name agreement effect for both object and action naming.

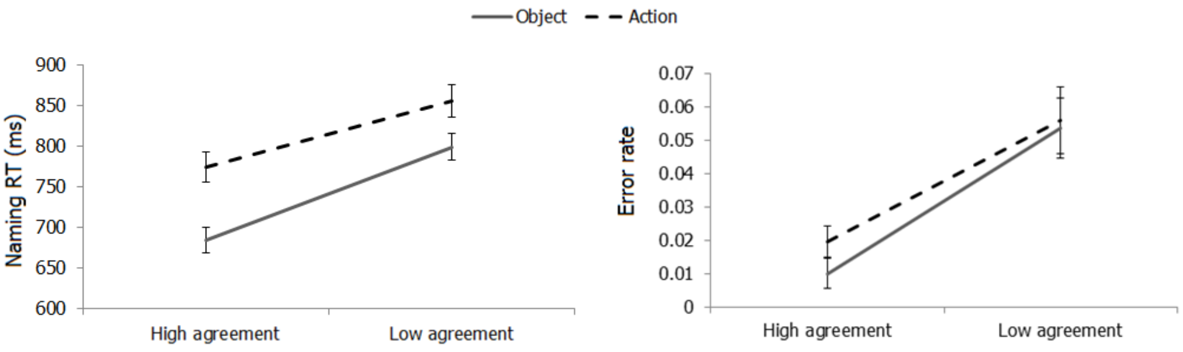

Figure 1. Naming RTs (left panel) and error rates (right panel) for action naming and object naming as a function of name agreement (high and low agreement). The error bars indicate standard errors (based on participant means).

ERP

Figure 2 displays the ERP results for the time window of 0-500 ms after picture onset. As in earlier studies, there is a P1 (peak at 50 ms), aligned with the pre-lexical stage of processing the pictures, followed by an N1 (peak at 120 ms), a P2 (peak at 170 ms), and an N2 (peak at 250 ms). Thus, the N2 was observed during the time window (170 - 330 ms) when lexical selection is likely to take place (i.e., 200-275 ms), according to Indefrey (2011; see also Costa et al., 2009; Indefrey & Levelt, 2004). As can be seen, there was little difference in the reaction to pictures with high and low naming agreement in the earliest time window (0-170 ms, the time window of the P1, N1, and P2), but differences are seen from about 170 ms onwards.

Separate statistical analyses of ERP amplitude were carried out for the earliest time window (0-170 ms) and the following window (170 - 330 ms) that covered the whole range of the N2 component in the low and high name agreement conditions for both object and action naming as shown in Figure 2. We used analyses of variance with three within-participants factors: name agreement (high vs. agreement), naming type (action or object), and quadrant (left anterior, left posterior, right anterior, right posterior) using participants as random variable. For the early time window (0-170 ms), we found no main effect of name agreement, $F(1, 20) = .24$, $p = .63$, or naming type, $F(1, 20) = 2.22$, $p = .15$, implying that the early processing for the high agreement and low agreement pictures, and for action and object pictures, was similar. But there was a main effect of quadrant, $F(3, 60) = 16.13$, $p < .001$, which appeared to indicate more activation in the posterior than other regions. No interaction between variables was found.

In the following time window (170 – 330 ms), we found a marginally significant effect of name agreement, $F(1, 20) = 4.14$, $p = .05$, but no main effect of naming type, $F(1, 20) = 0.7$, and no interaction between name agreement and naming type, $F < 1$. There was a main effect of quadrant, $F(3, 60) = 19.27$, $p < .001$, as well as a significant interaction between name agreement and quadrant, $F(3, 60) = 17.40$, $p < .001$, and a significant interaction between naming type and quadrant, *F*(3, 60) = 19.17, *p* < .001. Finally, we observed a significant interaction of all three factors, *F*(3, 60) = 4.36, *p* < .01.

To unravel the nature of the interactions, separate analyses were carried out for each of the four quadrants. These revealed a main effect of name agreement in left and right anterior quadrants, *F*(1, 20) = 6.77, *p* < .01 and *F*(1, 20) = 20.62, *p* < .001, respectively. Action naming showed a larger name agreement effect in the left anterior region than other regions, *F*(1, 20) = 5.23, *p* < .05. No interaction of name agreement and naming type was found in any of the quadrants.

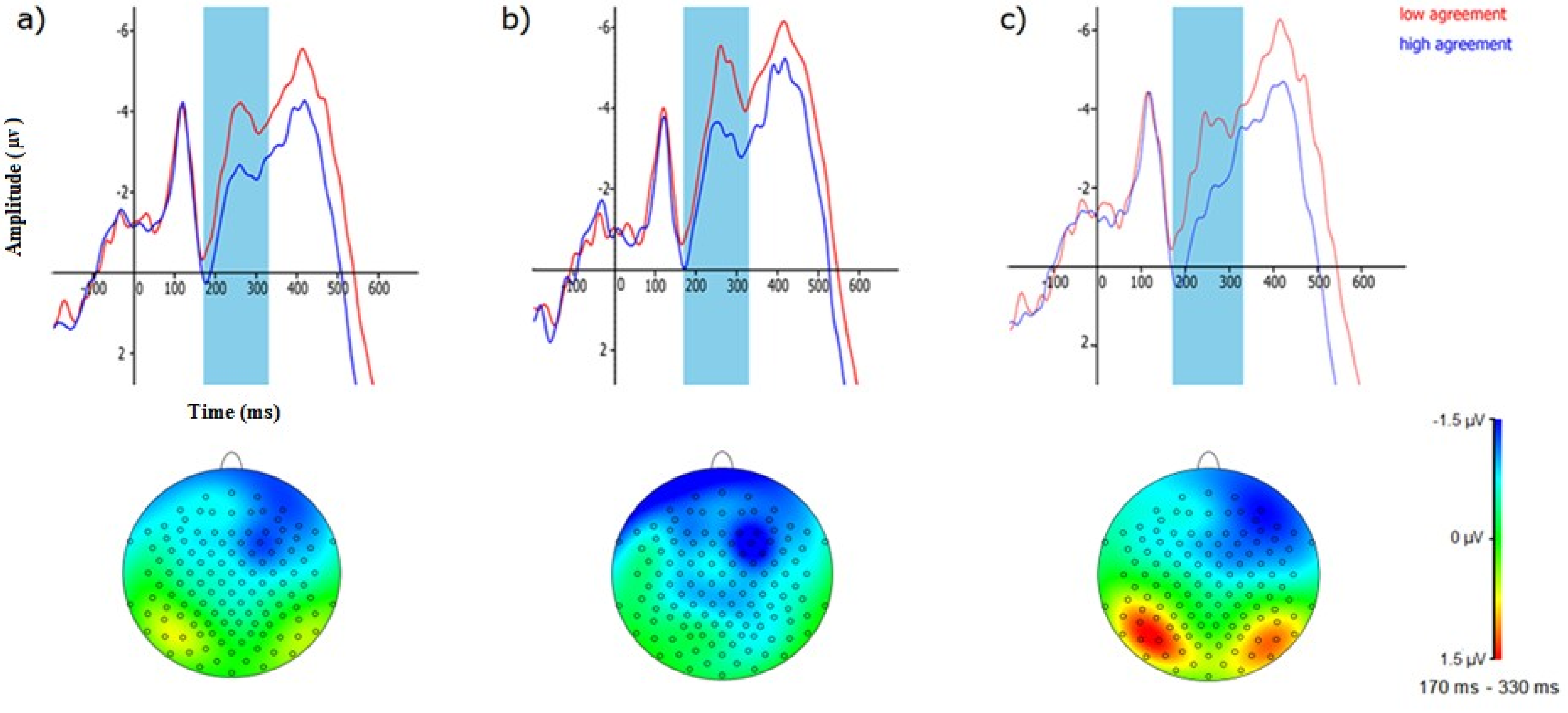

Figure 2. Grand averages for the ERPs in the low agreement (red line) and the high agreement (blue line) conditions, and scalp distribution maps for the 170 – 330 ms time window for the difference in average voltage between low and high agreement condition: (a) overall data, (b) action naming data, and (c) object naming data.

Correlation between name agreement effect and N2 effect

Finally, in order to assess the hypothesis that participants' name agreement effect on the naming RTs should be correlated with their inhibition ability as indexed by the N2 effect of name agreement, we correlated the magnitude of the N2 effect in the anterior quadrants (i.e., the N2 difference between low and high name agreement condition) and the magnitude of name agreement effect in the RTs (i.e., the naming RT difference between the low and high name agreement conditions). No correlation was found, $r = -.12$, $p = .61$. Figure 4 shows the scatter plots.

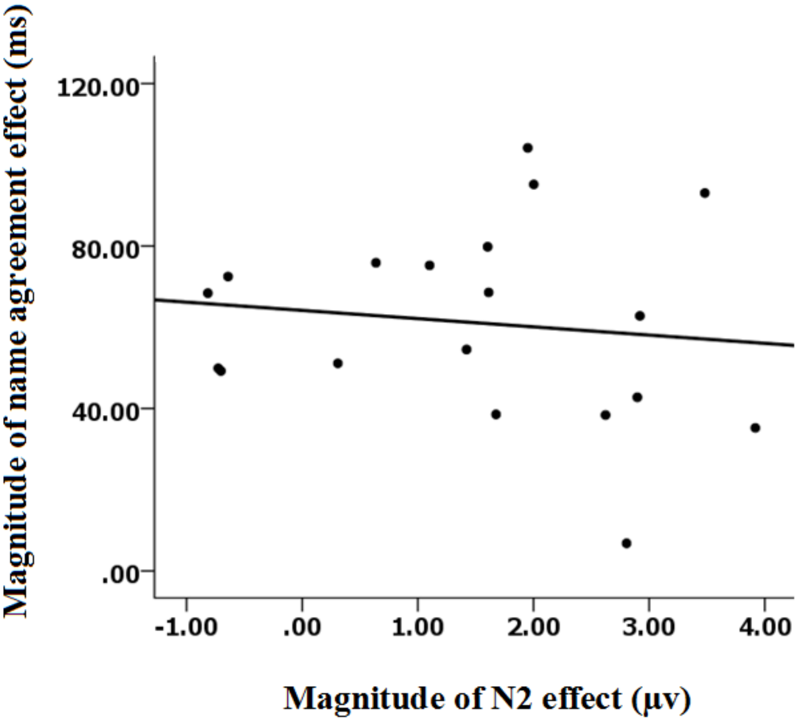

Figure 4. Scatter plot of the relationship between magnitude of the name agreement effect in the RTs and the magnitude of the N2 effect.

Discussion

Replicating numerous earlier studies (e.g., Alario & Ferrand, 1999; Barry et al., 1997; Shao, Roelofs et al., 2013, Chapter 5; Snodgrass & Yuditsky, 1996; Vitkovitch & Tyrrell, 1995), we found a name agreement effect on the naming RTs, which confirms our first hypothesis that speakers were faster to name pictures with high relative to low name agreement.

The effect of name agreement on the naming RTs, was stronger for pictures of objects than for pictures of actions though it was significant for both types of pictures. This difference in the size of the effect might be related to the fact that the contrast in name agreement (high-low) was larger for the object than for the action pictures.

As discussed in the Introduction, pictures can differ in name agreement for a number of reasons. Specifically, low name agreement may arise because speakers struggle to identify the depicted concept, or because they need to select among several names associated with a given concept (Vitkovitch & Tyrrell, 1995). Since the participants in our study were thoroughly familiarized with the pictures before the main experiment, we can rule a conceptual origin of the name agreement effect. Instead, it is likely that increased lexical competition for picture with low, compared to high, name agreement slowed down the naming responses.

The main goal of the study was to explore the involvement of inhibition in lexical selection. The indicator of inhibition we used was the amplitude of the N2 component of the ERP. Consistent with our second hypothesis, a more negative-going N2 in anterior regions was observed in the low than in the high name agreement condition. This N2 effect is consistent with studies using non-linguistic tasks that require strong response suppression (e.g., Bruin et al., 2001; Carriero et al., 2007; Dong et al., 2009), and studies that manipulated the difficulty of lexical access (e.g., Cheng et al., 2010; Costa et al., 2009; Laganaro et al., 2012).

It is important to point out that our assumption that the N2 component reflects inhibition ability is based on findings of other studies (e.g., Abdel Rahman et al., 2003; Bruin et al., 2001; Carriero et al., 2007; Dong et al., 2009; Verhoef et al., 2009).

Alternatively, the N2 may reflect conflict monitoring rather than inhibition, as suggested by Yeung et al. (2004). According to the conflict monitoring view, the amplitude of the N2 reflects the amount of response conflict detected by the anterior cingulate cortex (but see Aarts, Roelofs, & Van Turennout, 2008; Roelofs, Van Turennout, & Coles, 2006). The present study cannot distinguish between these alternatives. However, some previous evidence suggests that the N2 reflects inhibition rather than conflict monitoring in language performance. Verhoef et al. (2009) had Dutch-English bilinguals name pictures in Dutch or English. The target language was indicated by a cue presented 500 ms (short) or 1250 ms (long) before picture onset. Naming RTs were shorter for the long than short cue-picture intervals, whereas the amplitude of the N2 was larger for the long than short intervals. Under the conflict monitoring account, the amplitude of the N2 is expected to diminish with increasing cue-picture interval, given the corresponding decrease in naming RTs (suggesting decreased response conflict). However, Verhoef et al. observed the opposite: The amplitude of the N2 was larger for long than short cue-picture intervals. This finding challenges the conflict monitoring account and agrees with an inhibition account that assumes that inhibition takes time to build up over time (see Chapter 3; Ridderinkhof, 2002; Roelofs et al., 2011). Consequently, more inhibition can be applied during picture naming on long than short cue-picture intervals, which explains why the RT was shorter, and the N2 was larger, on long than short intervals. Future research may further examine the functional significance of the N2 in language performance.

We found that name agreement affected both the naming latencies and the amplitude of the N2. If these two observations are linked, regardless of whether the N2 component reflects on inhibition or conflict monitoring or both, one might expect the effect sizes for individual participants to correlated, such that participants with strong N2 effects should show strong effects of name agreement for the naming RTs. This was the third hypothesis formulated above. However, no such correlation was found. A possible account of this pattern is that the correlated measures were not sufficiently reliable. Given that the strength of a correlation is constrained by the reliability of the measurements (e.g., Spearman, 1904, 1927), low reliability will be attenuate the observed correlations. In the present study, the magnitudes of the agreement effect in the naming RTs and the N2 was calculated as a difference score, for which the reliability will be lower than for the measurements that make up the difference scores. Thus, it is possible that we found no correlation because the reliability of our measurements was insufficiently high.

As mentioned in the Introduction, Cheng and colleagues (2010) also investigated the effect of name agreement in an ERP study, but they used a covert object naming task. The N2 effect found in their study peaked at 290 ms, suggesting to them that the name agreement effect is located at the phonological encoding stage (e.g., Indefrey & Levelt, 2004; Indefrey, 2011). However, their argument was based on the assumption of a mean naming RT of 600 ms. The N2 of the present study peaked at 250 ms. However, the mean naming RT was 777 ms, which is longer by about 180 ms than the latency assumed by Indefrey and Levelt. If one proportionally adjusts Indefrey and Levelt's estimates, the estimated time interval for lexical selection in the present study is 260 – 360 ms. Then the N2 effect of the present study would peak just before or very early during lexical selection, when lexical concept are mapped onto lexical representations. However, regardless of whether the original estimates proposed by Indefrey and Levelt, or proportionally rescaled time windows are used, or data do not confirm the conclusion by Cheng et al. that the N2 occurred during phonological encoding.

Cheng et al. found that name agreement had a stronger effect in left parietal than other brain regions. In the present study, we found an effect in both left and right anterior regions, which corresponds more closely to the fronto-central distribution that is typically associated with an inhibition N2. The origins of this difference must be determined in further research.

Another difference between the present study and the study by Cheng et al. is that the latter study found an early effect of name agreement, manifested in the amplitude of the P1. According to Indefrey (2011; Indefrey & Levelt, 2004), P1 is associated with the visual and conceptual processes during picture naming. We did not observe the effect of name agreement on P1. Recall that the participants of the present study, but not those of the study by Cheng et al. were familiarized with the pictures so that effects of stimulus novelty and differences between the pictures with high and low name agreement in ease of recognition were minimized. This may have contributed to the confinement of the name agreement effect to the N2 component.

As explained in the Introduction, lexical selection is often seen as a competitive process (e.g., Abdel Rahman & Melinger, 2009; Bloem & La Heij, 2003; Howard et al., 2006; Levelt et al., 1999; Roelofs, 1992; Starreveld & La Heij, 1996). On this view, the selection of a target word is hindered by the co-activation of many, as compared to few, competitors, which may lead, among other things, to the effect of name agreement in picture naming. In the present study, we replicated this effect and we provided electrophysiological evidence from the N2 suggesting that lexical selection is more competitive when name agreement is low than when it is high. An alternative proposal concerning lexical selection is that this is not a competitive process (i.e., the response exclusion hypothesis; e.g., Finkbeiner & Caramazza, 2006; Mahon et al., 2007). Following this account, we should not observe that name agreement has an early effect, on the N2, during lexical selection. However, our results do show an early effect of name agreement on the N2, which support the lexical selection-by-competition account.

Finally, based on earlier findings reported in Shao et al. (2012, Chapter 2) we had expected that the N2 component would be more pronounced for action than for object pictures. This hypothesis was not borne out. The participants were slower to name action than object pictures, but this difference in the latencies was not accompanied by a corresponding difference in the magnitude of the N2 component. One account for this pattern is that object and action naming latencies differed for reasons other than differences in the involvement of inhibition. It could, for instance, be the case that the objects were easier to recognize than the actions, or that speakers generally find it easier to name objects than actions.

Conclusions

The present study provided ERP evidence for the engagement of inhibition during lexical selection: We found a larger N2 and longer naming RT in the low, relative to high, name agreement condition for both object and action naming. Taken together, the results are consistent with our proposal that inhibition is more strongly involved when lexical selection is more competitive.

Appendix A

Materials used in the experiment (English translations between parentheses).

Task	Picture name
Object naming	*High name agreement* anker (anchor), bad (bath), ballon (balloon), banaan (banana), bed (bed), blad (leaf), bloem (flower), boek (book), boom (tree), bot (bone), clown (clown), deur (door), doos (box), glijbaan (slide), heks (witch), hoed (hat), hond (dog), horloge (watch), kaars (candle), kaas (cheese), kam (comb), kicker (frog), koe (cow), leeuw (lion), lepel (spoon), mand (basket), neus (nose), oog (eye), radio (radio), schaar (scissors), sleutel (key), tafel (table), trammel (drum), varken (pig), veer (feather), vis (fish), vlag (flag), voet (foot), vork (fork), zon (son). *Low name agreement* been (leg), bijl (bell), brief (letter), brug (bridge), circus (circus), cirkel (circle), dieblad (tray), envelop (envelope), gewicht (weight), hek (gate), hersenen (brain), kaart (map), kantoor (office), kasteel (castle), kers (cherry), keten (chain), knoop (knot), kraag (collar), kruk (stool), ladder (ladder), nest (nest), ober (waiter), piano (piano), riem (belt), schaduw (shadow), schilderij (picture), serveerster (waitress), slaapkamer (bedroom), spleet (crack), strikijzer (iron), toerist (tourist), traktor (tractor), tunnel (tunnel), vijver (pond), weg (road), wortels (roots), zadel (saddle), zak (pocket), ziekenhuis (hospital), zwaard (sword).
Action naming	*High name agreement* aaien (stroke), bidden (pray), bijten (bite), blazen (blow), boren (drill), dansen (dance), drinken (drink), druppelen (drip), duwen (push), eten (eat), glijden (slide), huilen (cry), kammen (comb), kloppen (knock), knijpen (pinch), knippen (cut), koken (cook), kruipen (crawl), lachen (laugh), lezen (read), liken (lick), naaien (sew), regenen (rain), roeren (stir), roken (smoke), schieten (shoot), skieen (ski), slapen (sleep), sneeuwen (snow), springen (skip), strijken (iron), typen (type), fissen (fish), vliegen (fly), wegen (weigh), wijzen (point), zingen (sing), zinken (sink), zitten (sit), zwemmen (swim). *Low name agreement* aanraken (touch), aansteken (light), bouwen (build), breien (knit), brullen (roar), dragen (carry), drijven (drive), dromen (dream), duiken (drink), filmen (film), fluiten (whistle), gapen (yawn), glimlachen (smile), gooien (throw), graven (dig), jongleren (juggle), klimmen (climb), knielen (kneel), krullen (curl), kussen (kiss), leunen (lean), marcheren (march), niezen (sneeze), openen (open), roeien (row), salueren (salute), schaatsen (skate), scheppen (scoop), slopen (demolish), smelten (smelt), spelen (play), steken (sting), stuiteren (bounce), trekken (pull), vangen (catch), varen (sail), vouwen (fold), weven (wave), wiegen (rock), zweten (sweat).

Appendix B

Means of *H*-statistic and word frequency in high and low name agreement condition for object and action naming

		Name agreement	
Variable	Naming Type	High	Low
H-statistic	Object	.08	.75
	Action	.14	.93
Word frequency	Object	1.41	1.37
	Action	1.59	1.37

Chapter 7: Summary and Conclusions

Summary of the results

Several studies have shown that word production is affected by executive control processes. However, how and when executive control affects word production is still unknown. This thesis aimed to investigate the impact of important components of executive control on processes of single word production when healthy adults speaking in their native language. The main results are summarized below.

Chapter 2 investigated the contributions of three important components of executive control, namely shifting, updating, and inhibition, to individual differences in object and action naming latencies. We found that the speakers' updating and inhibition abilities were related to their naming latencies, whereas shifting ability was not related the naming latencies. When the naming latencies were submitted to ex-Gaussian analyses, the results showed that updating ability affected the proportion of very slow responses (i.e., the tail part of the naming latency distribution) for both object and action naming, suggesting that the updating ability influences concentration on the task and prevents lapse of attention. Inhibition affected the leading (main) part of the latency distribution for action naming and the tail part of the latency distribution of object naming. This pattern suggests that inhibition is more systematically engaged in action naming than object naming, most likely because more concepts are activated by complex action pictures, compared to simpler object pictures.

Chapters 3 and 4 further studied the effects of inhibition, and specifically aimed to tease apart the contributions of selective and nonselective inhibition in picture naming. Selective inhibition refers to the ability to suppress specific response competitors, and nonselective inhibition refers to the ability to stop any unwanted response. Chapter 3 used the picture-word interference task. Delta-plots were used to determine the strength of the semantic interference effect for faster and slower naming latencies. As explained above, the increase in the size of the effect across the latency continuum can be used to estimate whether or not selective inhibition was recruited in a tasks. Nonselective inhibition was indexed by the stop-signal response time (SSRT). Chapter 3 showed that the effects of selective and nonselective inhibition on picture naming can be separated to some extent. The efficiency of naming was indexed by two variables: magnitude of semantic interference effect (i.e., the naming latency difference between the semantically related condition and the unrelated condition) and absolute naming latencies. Selective inhibition was found to be only related to the size of the semantic effect, whereas nonselective inhibition was only related to the overall naming latencies. Moreover, there was no correlation between the measurements of selective and nonselective inhibition. These results suggest that selective inhibition is applied to reduce the activation of strong semantic competitors, whereas nonselective inhibition is applied to stop any irrelevant response.

Chapter 4 further investigated the effect of selective inhibition on naming performance. Three naming tasks were employed, namely the semantic blocking, picture-word interference, and color-word Stroop task. In line with the results of Chapter 3, selective inhibition was found to be related to the magnitude of the semantic interference and the blocking effect. This was not the case for nonselective inhibition. These results further support the hypothesis that selective inhibition, but not nonselective inhibition, is engaged in reducing semantic interference during picture naming. This is true when a single salient distractor is presented, as is the case in the semantic interference paradigm, and when strong competitors are evoked through the preceding context, as is the case in the semantic blocking paradigm. Interestingly, performance in the Stroop task was not related to selective inhibition, suggesting that the engagement of selective inhibition during competition may be optional.

Chapter 5 presents a norming study of line drawings of actions used in this thesis. It provides normative data from Dutch speakers for several important variables of action naming, including visual complexity, imageability, image agreement, name agreement, age-of-acquisition, familiarity, word frequency and length as well as naming latencies. Multiple regression analyses showed that name agreement, image agreement, imageability, visual complexity, and age of acquisition were significant predictors of action naming latencies. Principle component analyses indicated that variables influencing the processes of conceptualization and lexical selection made the strongest contribution to the action naming latencies, whereas variables influencing the processes of phonological encoding or syllabification made small contribution.

Finally, in Chapter 6, I explored the neural basis of inhibition that is engaged when different degrees of competition arise because of high/low name agreement, i.e. when a single concept is associated with one or several words. Object and action pictures were used. Action pictures were selected using the new norms described in Chapter 5. The results of Chapter 6 showed a larger N2 effect at anterior brain regions in the low than the high name-agreement condition.

Contributions of executive control to word production

According to the model of Miyake et al. (2000), there are three main components of executive control: shifting, updating, and inhibition. This thesis shed new light on their role during single word production. In the following section, the effects of the individual components of executive control on word production are discussed.

First, the shifting ability was not found to have a major impact on the participant's naming performance, which, given the uniformity of the task (object or action naming on all trials) is not surprising. The present results do not exclude that shifting may play a crucial role in other linguistic tasks, for instance, when language switching or even, in dialogue, switching between listening and speaking is required. This could be studied in further research.

Second, the updating ability, measured through the operation span task, was shown to be related to naming performance in Chapter 2. As discussed above, it appeared to be more systematically involved in action naming - the harder task - than in object naming. Evidence that the updating ability is especially important when the object naming task is difficult comes from a recent dual-task study by Piai and Roelofs (2013). Their participants had to name object pictures with superimposed distractor words (cf. Chapter 4 of this thesis) and concurrently make a tone discrimination requiring a manual response. Updating ability not only correlated with object naming latencies (cf. Chapter 2 of this thesis) but also with the magnitude of the dual-task interference from tone discrimination on picture naming. Exactly how updating ability affects naming performance needs to be determined in further research. An important step in such a research programme would be to measure updating ability in more than one way, and to measure other cognitive skills, which are likely to be correlated with updating ability, as well. For instance, updating is strongly related to fluid intelligence (cf. Kane & Engle, 2002), and it would be important to determine whether both have independent effects on naming performance. In addition, it should be fruitful to investigate the role of updating in more complex speech production tasks (for instance the production of sentences) and to determine whether or not updating ability has a stronger influence as task complexity increases. One might also compare the impact of updating ability in speech production and comprehension tasks of comparable complexity in order to understand the impact on various components of the speech processing system.

Third, the inhibiting ability was examined in most of the chapters of this thesis. All relevant experiments showed that inhibition systematically affected the speakers' naming performance. However, the results of this thesis also indicate a complex role for inhibition during word production. According to the literature, inhibition is not a unitary construct but a set of closely related abilities (e.g., Castner et al., 2007; Friedman & Miyake, 2004; Krämer et al., 2011; Nigg, 2000; Spaulding, 2010). In this thesis, I studied effects of two types of inhibition during word production, and moreover I found that selective and nonselective inhibition were to some extent separable. As explained above, nonselective inhibition was measured using stop-signal RT. The involvement of selective inhibition in the naming task was inferred from the inspection of the delta-plots for the naming latencies.

The first type is called nonselective inhibition, which is assessed by stop-signal task. In Chapters 2 and 3, we consistently found a correlation between stop-signal reaction time and naming latencies, suggesting that nonselective inhibition plays an important role in overall naming speed. However, such a correlation was not found in Chapter 4. But it is important to note that in Chapter 4, the pictures used in the two naming tasks were repeated multiple times. With multiple repetitions, the stimuli become increasingly familiar and the level of interference may be reduced so that nonselective inhibition is less needed. Similarly, in Chapter 2, the correlation between stop-signal reaction time and naming latencies was stronger with action than object naming. Compared to object naming, action naming is more complex and presumably triggers more interference. Consistent with this hypothesis, a substantial positive correlation between stop-signal reaction time and naming latencies was observed in the first trial block for both naming tasks in Chapter 4. Thus, complex and novel pictures may active more interference representations so that nonselective inhibition is more likely to be engaged.

The second type of inhibition studied in the thesis is called selective inhibition. This type of inhibition may be assessed through delta plot analyses, and is reflected in the slope of the slowest delta segment of the RT distributions of picture-word interference and semantic blocking tasks. In Chapters 3 and 4, selective inhibition was found to be correlated with the magnitude of the semantic interference effect, suggesting that selective inhibition helps to reduce strongly co-activated competitors. However, the indicator of semantic interference and selective inhibition were derived from the same dependent measure - the picture naming latency. In further research, it would be interesting to determine whether there are stable differences between speakers in their general ability or propensity to engage selective inhibition in linguistic and nonlinguistic tasks. Chapter 6 explored the neural mechanism of selective inhibition during word production. The N2 effect suggests that inhibition support lexical selection by suppressing competitors.

Important goals for future research should be to find ways of assessing both nonselective and selective inhibition in multiple ways, and to assess their involvement in other speech production and comprehension tasks. For instance, the present thesis focused on the lexical selection process during single word production, future work should examine the role of executive control in the morphological and phonological encoding or articulatory planning phrases as well. Such research should lead to a refined picture of the involvement of general cognitive skills in speaking and listening.

Taken together, the findings of this thesis indicate a crucial role of two components of executive control during word production. Updating helps to monitor and keep track of the goal relevant representations in memory, and inhibition helps to stop unwanted responses or suppress strong semantic competitors.

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Samenvatting

Spreken wordt, net als andere doelgerichte activiteiten, gestuurd door hogere cognitieve mechanismen, waaronder controlefuncties. Er is echter weinig bekend over hoe en wanneer controlefuncties een rol spelen tijdens woordproductie. In dit proefschrift is de rol van verscheidene belangrijke controlefuncties onderzocht bij de productie van afzonderlijke woorden door gezonde volwassenen in hun moedertaal.

In hoofdstuk twee is onderzocht hoe drie belangrijke controlefuncties, omschakelen, updaten en inhibitie, bijdragen aan individuele verschillen in de snelheid van het benoemen van objecten en acties. De uitkomsten van correlatie-analyses suggereren dat het vermogen om te updaten invloed heeft op de concentratie tijdens een taak en dat het ervoor zorgt dat de aandacht niet afdwaalt. Daarnaast is inhibitie sterker betrokken bij het benoemen van acties dan bij het benoemen van objecten, waarschijnlijk omdat er meer concepten worden geactiveerd bij het zien van complexe acties dan bij het zien van simpele objecten.

In hoofdstuk drie en vier zijn de effecten van inhibitie onderzocht met het doel onderscheid te maken tussen de bijdragen van selectieve en niet-selectieve inhibitie bij het benoemen van plaatjes. Selectieve inhibitie heeft te maken met het vermogen om specifieke alternatieve reacties te onderdrukken en niet-selectieve inhibitie heeft betrekking op het vermogen om elke ongewilde reactie te stoppen. In hoofdstuk drie wordt aangetoond dat selectieve inhibitie invloed heeft op het effect van semantische concurrenten, terwijl niet-selectieve inhibitie invloed heeft op de algehele benoemsnelheid. De resultaten suggereren dat selectieve inhibitie wordt toegepast om

de activatie van sterke semantische concurrenten te verminderen, terwijl niet-selectieve inhibitie wordt toegepast om elke ongewilde reactie te stoppen.

In hoofdstuk vier werd het effect van selectieve inhibitie onderzocht op benoemgedrag in drie taken: de semantisch geblokte benoemtaak, de plaatje/woord-interferentietaak en de kleur/woord-Strooptaak. De resultaten ondersteunen de hypothese dat selectieve inhibitie betrokken is bij het verminderen van semantische interferentie tijdens het benoemen van plaatjes. Dit geldt wanneer een enkel opvallend concurrentiewoord aanwezig is, zoals het geval is bij de plaatje/woord-interferentietaak, en wanneer sterke concurrenten worden geactiveerd door de voorafgaande context, zoals het geval is bij de semantisch geblokte benoemtaak. Interessant genoeg werd er geen verband gevonden tussen prestaties in de 'Stroop'-taak en selectieve inhibitie, wat suggereert dat de betrokkenheid van selectieve inhibitie tijdens concurrentieprocessen optioneel is.

In hoofdstuk vijf werd een normeringsstudie gerapporteerd van de plaatjes van de acties die gebruikt zijn in dit proefschrift. Het toont normatieve data van Nederlandse sprekers voor verschillende belangrijke variabelen bij het benoemen van acties, waaronder visuele complexiteit, voorstelbaarheid, beeldovereenstemming, naamovereenstemming, verwervingsleeftijd, bekendheid, woordfrequentie en -lengte, als ook de benoemsnelheid. De resultaten lieten zien dat naamovereenstemming, beeldovereenstemming, voorstelbaarheid, visuele complexiteit en verwervingsleeftijd significante voorspellers zijn voor actiebenoemsnelheid, en dat de variabelen die de processen van conceptualisatie en lexicale selectie beïnvloeden het meeste bijdragen aan de actiebenoemsnelheid.

Tot slot werd in hoofdstuk zes de neurale basis van inhibitie verkend die betrokken is bij verschillende gradaties van competitie veroorzaakt door hoge/lage naamovereenstemming (wanneer een concept geassocieerd wordt met een enkel woord of juist met meerdere woorden). De resultaten lieten een groter N2-effect over de voorste hersengebieden zien wanneer er een lage naamovereenstemming was dan wanneer er een hoge naamovereenstemming was.

Samenvattend kan worden gesteld dat de bevindingen van dit proefschrift erop wijzen dat twee controlefuncties een cruciale rol spelen tijdens woordproductie. Updaten helpt tijdens het spreken bij het controleren van en toezicht houden op representaties in het geheugen die relevant zijn voor het doel. Inhibitie helpt ongewilde reacties te stoppen of sterke semantische concurrenten te onderdrukken.

中文概述

就像其他有目的的行为一样，词语产生的过程也受到了一些自上而下的认知机制的影响，比如执行控制。然而，目前学术界还不清楚执行控制是如何以及何时影响词语的产生。因此本论文着重研究了这个问题。

首先，第二章研究了执行控制的三种重要因素，包括转换，及时更新和抑制的能力，是如何影响成人命名物体和动作图片的速度。结果显示及时更新的能力帮助人们更好的集中在实验任务上以避免偶尔的注意力分散。同时命名动作图片的时间受到抑制能力的影响。这可能是因为当人们命名动作图片的时候，会激活更多的概念，所以更需要抑制能力来消除这些概念的干扰。

第 3 和第 4 章研究了选择性和非选择性抑制能力对物体图片命名的过程的影响。选择性的抑制能力是指抑制某些特别的概念的能力；而非选择性的抑制力是指抑制所有无关反应的能力。第 3 章发现选择性的抑制能力只和语义干扰效果的大小相关，而不和图片命名的速度相关。非选择性的抑制力只和图片命名的速度相关，而不和语义干扰的效果的大小相关。这说明选择性的抑制能力是用来抑制与干扰词相关的被激活的概念，而非选择性的抑制能力是用来抑制和实验无关的信息。

第 4 章研究选择性抑制能力和语义分块，图词干扰和色词 Stroop 三种命名任务的关系。结果显示选择性的抑制能力和语义分块以及图词干扰命名任务的干扰效果的大小相关。这表明，选择性抑制能力是用于抑制语义干扰。然而，选择性抑制能力跟色词 Stroop 命名任务的干扰效果不相关。我们怀疑这是

因为色词 Stroop 任务过难，人们很难在短时间内有效地运用选择性抑制能力来帮助命名的过程。

第 5 章提供了本论文中使用到的动作图片的规范性数据，包括这些图片的视觉复杂度，想象度，图片认同度，名字认同度，习得年龄，熟悉度，词语频率，长度，以及命名时间。研究结果表明概念形成和词汇选择的过程比语法和音系编码的过程对动作图片的命名的影响更大。

第 6 章通过脑电图的方法在脑机制的层面上研究抑制能力在词语提取中的作用。我们使用了名字认同度不同的图片。当一幅图片的名字认同度高的时候，只有一个概念被激活；当一幅图片的名字认同度低的时候，相对比较多的概念被激活。我们发现当人们命名名字认同度低的图片的时候，脑右前区会出现的更大的 N2 的效果。而 N2 在学术界被认为是运用抑制能力的指标。所以，我们的结果表明在图片命名的过程中，抑制力被运用于支持词语提取。

总体来说，执行控制能力在词语产生过程中起到了关键性的作用。具体而言，及时更新能力帮助人们在说话时检查任务目标以及在记忆中不断追踪与任务相关的内容；抑制能力一方面帮助人们抑制不相关的信息，另一方面抑制被激活的相关的竞争性的语义概念。

Acknowledgements

It is a great honor to carry out my Ph. D. project in Max Planck Institute for Psycholinguistcs. All challenges, excitement and improvement in the last three years make it most memorable in my life. During this period I learned how to perform scientific research and to broaden my horizons. I would like to take this opportunity to show my gratitude to many people. This thesis would not have been possible without their guidance and help.

First and foremost, I offer my utmost gratitude to my supervisors: Prof. dr. Antje Meyer and Dr. Ardi Roelofs. I benefited so much by your enriched knowledge, thoughtful ideas and valuable suggestions. I am so proud to be your student. Danke sehr, Antje! I owe my deepest appreciation to you. Thank you for providing me with unflinching encouragement and support in various ways. Dank u wel, Ardi! Thank you for steering me in the right direction and providing me with insighful suggestions all the time.

Next, I would like to thank Dan Acheson for your valuable suggestions for my EEG study and Randi Martin for your great idea to motivate my Chapter 3. I would also like to thank members of the manuscript committee: Prof. dr. Herbert Schriefers (chairman), Prof. dr. Eva Belke and Prof. dr. Markus Damian for spending time and effort to read and assess my thesis.

It is a great pleasure to work in the Psychology of Language Department. I am greatly indebted to all my colleagues: Agnieszka Konopka, Alastair Smith, Alma Veenstra, Aoju Chen, Annelies van Wijngaarden, Carmen Paduraru, Cornelia Moers, Evelyn Giering, Falk Huettig, Florian Hintz, Jana Reifegerste, Joost Rommers, Lesya

Ganushchak, Loan Vuong, Maartje van de Velde, Matthias Sjerps, Suzanne Jongman, and Svetlana Gerakaki. Thank you for all your helps with practical matters of my Ph. D. project. We are not only colleagues but also good friends. I will never forget the fun moments in and outside the office.

Many thanks go in particular to my paranimfen: Joost Rommers and Wencui Zhou, for taking time to help me to organize my defense party. Joost, dear officemate, thanks for you to answer my endless questions about Dutch and to share all my frustrations and successes. Dear Wencui, my sweet friend, thank you for all the delicious food and warm messages.

I am also greatly thankful to Danchao Cai, Haiteng Jiang, Jiyoun Choi, Vitória Piai, Yan Gu, Salomi Asaridou, and other friends in MPI and Radboud University.

I would also thank to the staff from Administration and Technique Group for their help during my Ph. D. tenure.

Finally, I would like to thank my parents, my dear husband -- Mingyuan, my lovely son -- Peter and other family members. This work would not have been possible without your unconditional love, unending support and encouragement. I love you all! 我爱你们！

Curriculum Vitae

Zeshu Shao was born on June 10th, 1982 in Shanxi, China. She studied Applied Psychology at Nankai University in China and obtained a Bachelor’s degree in 2004. In 2005, she obtained a Master’s degree at University of Nottingham in UK. Then she worked as research assistant with Professor Sotaro Kita from 2006 to 2009 at University of Birmingham in UK. Since October 2009, she started her PhD at University of Birmingham and moved to Max Planck Institute for Psycholinguistics one year later. In 2013, she continues her research as research staff at Max Planck Institute for Psycholinguistics.

List of Publications

Shao, Z., Roelofs, A., Acheson, D. J., & Meyer, A. S. (2013). *Electrophysiological evidence that inhibition supports lexical selection in picture naming.* Manuscript submitted for publication.

Shao, Z., Roelofs, A., Martin, R., & Meyer, A. S. (2013). *Selective inhibition and naming performance in semantic blocking, picture-word interference, and color-word Stroop tasks.* Manuscript submitted for publication.

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