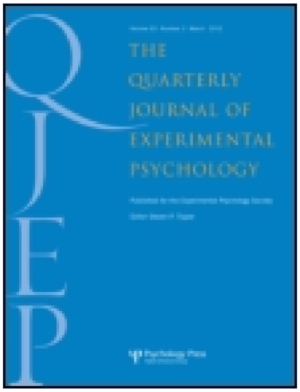

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Sources of individual differences in the speed of naming objects and actions: The contribution of executive control

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We examined the contribution of executive control to individual differences in response time (RT) for naming objects and actions. Following Miyake et al., 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.

Keywords: Object naming; Action naming; Individual differences; Executive control; Updating; Inhibition.

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 prelinguistic processes leading to the selection of a concept to be expressed, lexical retrieval processes leading to the retrieval of the syntactic and morphophonological properties of the word, and postlexical 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).

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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 be tested not only experimentally, but also by examining the predictions they make about individual differences. If a cognitive component, A, plays a nontrivial 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 experiments 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., Badre, Poldrack, Paré-Blagoev, Insler, & Wagner, 2005; Thompson-Schill et al., 1998). Studies of ADHD have indicated that deficient inhibiting abilities caused disfluencies during sentence production (e.g., Engelhardt, Corley, Nigg, & Ferreira, 2010). In the ageing 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., Festman, Rodriguez-Fornells, & Münte, 2010; Luo, Luk, & Bialystok, 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 conceptualized 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 that 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 et al., 2006; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). They distinguish three types of executive control abilities: (a) monitoring and updating of working memory representations, henceforth "updating", (b) inhibiting of dominant responses, henceforth "inhibiting", and (c) shifting of tasks or mental sets, henceforth "shifting".

Though the framework of Miyake and colleagues (e.g., Friedman et al., 2006; Miyake et al., 2000) 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 experiments that examined whether indicators of executive control ability correlated with performance speed in picture-naming tasks. In both experiments, 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 et al., 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 experiments, 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, $M_{\text{age}} = 19.1$ 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 database (Baayen, Piepenbrock, & Van Rijn, 1993) (mean word form frequencies/million: $M_{\text{object}} = 7.09$, $SD = 7.24$, $M_{\text{action}} = 9.28$, $SD = 20.38$), $F(1, 111) = 0.54$, $p = .47$. 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 1,400 ms to remind the participants to speed up. The interstimulus interval was 1,500 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 2,000 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 maths 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 that 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—for example, (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 min. 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 maths 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 maths 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 maths 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, $M = 35.57$; $SD = 9.68$; Unsworth & Engle, 2005, $M = 13.25$; $SD = 6.58$).

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 response times (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*

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

Note: Latencies are given in milliseconds. SD = standard deviation.

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, $r = .744$, $p < .01$. 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, $r = -.415$, $p < .05$, $r = -.266$, $p = .172$, 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 tasks described below.

Moreover, we examined the correlations of measures of executive control not only with the participants' mean RTs in the naming tasks, but also with parameters characterizing 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 Süß, and Wittmann (2007) identified latent factors for each of the three ex-Gaussian parameters using structural equation modelling 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, $M_{age} = 21.63$ years, age 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. 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 those 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 seven-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 10 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 analysed 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 × 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 1,250 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 that 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–colour 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 coloured 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 colour (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 the square). There were six blocks (i.e., two colour blocks, two shape blocks, and two mixed blocks). Each colour and shape blocks included 48 trials, and each mixed blocks included 128 trials. In the colour 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 colour. 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 colour 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 colour 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 RTs 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–colour shifting latencies.

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

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–colour shifting latency*

	Latency		
	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–colour	394	187	7.00

Note: Latencies are given in milliseconds. *SD* = standard deviation.

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–colour	.36	.36	−.10	.45*

*Correlation is significant at the .05 level (two-tailed). **Correlation is significant at the .01 level (two-tailed).

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.

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–colour 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 experiments 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 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 study 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 experiments, 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 experiments, and we 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, and 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 those 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, 2012), 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 reaccessed, 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 experiments, 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.[1] 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 others 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

[1] We thank anonymous reviewers for suggesting this possibility.

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, $t(160) = 0.91$, $p = .36$ 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 those 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., Cook & Meyer, 2008; Ferreira & Pashler, 2002; 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 experiments, 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 components 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 activate not only the response *cat*, but also responses like *feline*, *animal*, *tail*, *dog*, and so forth. Likewise, a picture of a man kicking a ball may activate not only 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 object naming and μ of action naming. As for updating, more research is required to determine exactly how inhibiting ability is involved in naming. In a companion study (Shao et al., 2012), 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 experiments), 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 taps not only 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 an even 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 participant 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 not only is 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 nontrivial 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

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.

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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 experiments	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 experiments	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

	Overall	
Indexes	*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