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# Switching between spoken language-production tasks: the role of attentional inhibition and enhancement

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**ABSTRACT**
Since Pillsbury [1908. *Attention*. London: Swan Sonnenschein & Co], the issue of whether attention operates through inhibition or enhancement has been on the scientific agenda. We examined whether overcoming previous attentional inhibition or enhancement is the source of asymmetrical switch costs in spoken noun-phrase production and colour-word Stroop tasks. In Experiment 1, using bivalent stimuli, we found asymmetrical costs in response times for switching between long and short phrases and between Stroop colour naming and reading. However, in Experiment 2, using bivalent stimuli for the weaker tasks (long phrases, colour naming) and univalent stimuli for the stronger tasks (short phrases, word reading), we obtained an asymmetrical switch cost for phrase production, but a symmetrical cost for Stroop. The switch cost evidence was quantified using Bayesian statistical analyses. Our findings suggest that switching between phrase types involves inhibition, whereas switching between colour naming and reading involves enhancement. Thus, the attentional mechanism depends on the language-production task involved. The results challenge theories of task switching that assume only one attentional mechanism, inhibition or enhancement, rather than both mechanisms.

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In daily life, people must often switch between tasks, such as between writing an email and answering the phone, each of which is governed by a task set that specifies the required processes. In the past few decades, research on task switching has been dominated by studies of switching between simple tasks requiring discrete manual or vocal responses (e.g. Monsell, 2015, for a review). For example, participants had to switch between parity (odd/even) and magnitude (larger/smaller than five) judgments in response to digits, or between colour naming and word reading in response to colour-word Stroop stimuli. Switch costs concern the difference in response time (RT) between trials that repeat the task of the previous trial (repeat condition) and trials in which the task is different from the previous trial (switch condition). Asymmetrical switch costs (i.e. a larger cost for one task than the other) have been repeatedly observed in switching between tasks of different strengths, like colour naming and word reading (e.g. Philipp, Gade, & Koch, 2007; see Koch, Gade, Schuch, & Philipp, 2010, for a review). Larger costs are obtained for switching to the stronger tasks, such as word reading in case of Stroop task-switching (e.g. Allport & Wylie, 1999, 2000). However, asymmetrical switch costs are not always obtained for tasks of different strength, but symmetrical costs may be obtained as well under certain circumstances (e.g. Yeung & Monsell, 2003).

Recently, asymmetrical switch costs were obtained for switching between more complex nondiscrete tasks, in particular, for switching between types of noun phrases in spoken picture description (Sikora, Roelofs, & Hermans, 2016; Sikora, Roelofs, Hermans, & Knoors, 2016). Participants switched between short and long phrases (e.g. between saying "the fork" and "the green cup", or vice versa). Switching in phrase production yielded a larger cost for switching to short phrases (e.g. "the fork", the stronger task) than to long phrases (e.g. "the green cup", the weaker task). The asymmetrical switch cost may be explained in terms of task-set inertia involving attentional inhibition of the stronger task set, as has been proposed in the task-switching Stroop literature (e.g. Allport & Wylie, 1999, 2000). However, as we explain below, it has remained unclear whether Stroop switching actually involves attentional inhibition or enhancement of task sets. Since Pillsbury (1908), it is often acknowledged that attention may operate through inhibition or enhancement depending

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on the task and experimental circumstances. However, theories of task switching tend to place emphasis on either inhibitory or non-inhibitory mechanisms. Whereas Allport, Styles, and Hsieh (1994) and Meuter and Allport (1999) emphasised inhibition, more recent theoretical accounts assume no role for inhibition (Bryck & Mayr, 2008; Schneider & Anderson, 2010; Yeung & Monsell, 2003). The aim of the research reported in the present article was to examine the source of asymmetrical switch costs (i.e. inhibition or enhancement) by directly comparing switching in noun-phrase production and in colour-word Stroop tasks. The outcomes of our research have theoretical value as they provide additional evidence on a century-old issue, namely whether attentional inhibition, enhancement, or both may be engaged, depending on the tasks and circumstances. A further clarification of this issue contributes to the task switching literature. More specifically, evidence that inhibition or enhancement is engaged depending on the tasks and experimental circumstances would challenge theories of task switching that assume only one attentional mechanism (i.e. Allport et al., 1994; Bryck & Mayr, 2008; Meuter & Allport, 1999; Schneider & Anderson, 2010; Yeung & Monsell, 2003).

Stroop task-switching involves oral responses for reading and colour naming, which are language tasks that individuals also perform outside the laboratory, although they normally do not switch back and forth between reading and naming. However, individuals regularly switch between long and short phrases in normal conversations. For example, in saying "the green cup is next to the fork", a speaker switches between a noun phrase with an adjective ("the green cup") and one without ("the fork"). Thus, the attentional mechanisms involved in switching between phrase types in the laboratory are likely also commonly involved in normal conversations in daily life.

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

## Asymmetrical switch costs and task-set inertia

In task switching, asymmetrical switch costs have often been obtained. For example, in a study investigating switching between languages, Meuter and Allport (1999) observed a larger switch cost for switching to the stronger first language than to the weaker second language of bilingually-unbalanced speakers. A similar switch cost asymmetry has often been reported for the colour-word Stroop task when participants switch between colour naming and word reading. In the Stroop task, participants name the ink colour of incongruent colour words (e.g. the word *red* in green ink) or neutral series of Xs, or alternatively, they read aloud the incongruent colour words or words in neutral black ink (e.g. MacLeod, 1991). The switch cost in RTs is larger for switching to the stronger reading task than to the weaker colour naming task (e.g. Allport & Wylie, 1999, 2000).

We take tasks to differ in strength when they differ in the amount of practice, complexity, or stimulus-response compatibility (cf. Yeung & Monsell, 2003). Strength is typically reflected in the mean RT if the tasks are performed in isolation. For example, due to different degrees of practice, mean RT is typically shorter for picture naming in the first (native) language than in a second (foreign) language (although in language switching, the difference in RT may be reversed, e.g. Verhoef, Roelofs, & Chwilla, 2009). Similarly, mean RT is typically shorter for Stroop reading than Stroop colour naming, which seems due to differences in the amount of practice, task complexity, and stimulus-response compatibility. The mean RT is typically shorter for the production of short noun phrases than for long noun phrases, which is due to the greater complexity of the latter.

To explain the paradoxical switch cost asymmetry (i.e. a larger switch cost for the stronger task), Allport and colleagues proposed a task-set inertia account. According to this account, when performing a weaker task (e.g. colour naming or naming in a second language), its task set must be enhanced or the task set of the irrelevant stronger task (e.g. word reading or naming in the first language) must be inhibited. Consequently, in switching from the weaker task to the stronger task, the previous enhancement of the weaker task or the previous inhibition of the stronger task must be overcome, which will increase RTs. In contrast, in switching from the stronger task to the weaker task, there is no such or less previous enhancement of the target task on the previous trial (which was the stronger task) or previous inhibition of the irrelevant task (which was the weaker task), and RTs will not be increased (as much). As a result, a smaller difference in switch cost compared to switching in the opposite direction will be obtained.

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

## Attentional inhibition versus enhancement of task set

The results of Allport and Wylie (1999, 2000) support the task-set inertia account. However, the results are silent about inhibition and enhancement. In the all-neutral and colour-neutral/word-incongruent conditions, symmetrical switch costs were obtained for word reading and colour naming, whereas the switch cost was much larger for word reading than for colour naming in the all-incongruent condition. In naming the colour of incongruent colour-word combinations (required only in the all-incongruent condition), the task set for colour naming may be enhanced, the task set for reading may be inhibited, or both. To explain the asymmetrical switch cost, it suffices to assume either enhancement of the weaker task set or inhibition of the stronger task set. For example, to explain the asymmetrical switch costs between colour naming and reading, it suffices to assume that the task set for colour naming is enhanced on colour naming trials, whereas there is no such enhancement of the task set for reading on reading trials. Alternatively, it may be assumed that the task set for reading is inhibited on colour naming trials, whereas there is no or less inhibition of the task set for colour naming on reading trials. The existing results do not allow for a distinction between inhibition and enhancement of task set in Stroop task-switching. Evidence from nonswitching Stroop colour naming suggests that inhibition is not involved (Lamers, Roelofs, & Rabeling-Keus, 2010; Pratte, Rouder, Morey, & Feng, 2010; Shao, Roelofs, Martin, & Meyer, 2015). This would make Stroop task switching different from switching between types of noun phrases, where the available evidence suggests that inhibition is involved, as we indicate next.

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

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

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

In support of their inhibition account, Sikora, Roelofs, and Hermans (2016) reported evidence from event-related brain potentials (ERPs) recorded during the planning of noun phrases of different length on switch and repeat trials. Previous ERP research on language performance (Verhoef et al., 2009, 2010) has suggested that inhibition and overcoming inhibition are associated with, respectively, anterior and posterior subcomponents of the N200, which is a negative-going deflection in the ERP observed approximately 200–350 ms after stimulus onset. Sikora et al. observed a switch cost in the RTs for the short phrases but not for the long phrases. The amplitude of the anterior N200 was larger for the long phrases than for the short phrases, suggesting greater inhibition of the task set for the short phrases on long-phrase trials than for the long phrases on short-phrase trials. In the posterior N200, the reverse effect was obtained on switch trials, suggesting greater difficulty in overcoming previous inhibition for the short phrases than for the long phrases. These findings support the inhibition account of the asymmetrical cost in switching between phrases of different length, which is in line with the account of Meuter and Allport (1999) of switching between languages of different strength. However, the findings are difficult to explain by accounts of asymmetrical switch costs that assume no role for inhibition, such as the differential long-term trace account of Bryck and Mayr (2008), the sequential difficulty account of Schneider and Anderson (2010), the differential repeat-benefit account of Verhoef et al. (2009), and the enhancement-only account of Yeung and Monsell (2003).

## *Outline of the present study*

We conducted two experiments to obtain further evidence that the cost of switching between phrase types reflects inhibition, and to examine whether switching between Stroop colour naming and reading involves inhibition or enhancement. In both experiments, participants performed both the phrase production task and the colour-word Stroop task. In Experiment 1, we used bivalent stimuli for both phrase production and Stroop. Trials were blocked by type of language task (i.e. phrase production or Stroop). Stimulus presentation and task cuing was different from Sikora, Roelofs, and Hermans (2016) and Sikora, Roelofs, Hermans et al. (2016), where pictures were presented in the middle of a computer screen and the task changed every second trial without explicit cuing. On successive trials in the present experiments, the stimuli (i.e. picture or colour-word stimuli) were presented in clockwise rotation in different quadrants of a computer screen, so that the quadrants cued the tasks. Participants had to perform one task (e.g. short phrases, word reading) when the stimuli appeared in the upper part of the screen and the other task (e.g. long phrases, colour naming) when the stimuli appeared in the lower part. We expected to obtain asymmetrical switch costs for both the phrase production task and the colour-word Stroop task. This would replicate the Stroop task findings of Allport and Wylie (1999, 2000), who obtained an asymmetrical switch costs in their all-incongruent condition. Moreover, this would show that the findings of Sikora, Roelofs, Hermans et al. (2016) and Sikora, Roelofs, and Hermans (2016) are also obtained when participants produce the short and long phrases always in response to coloured pictures. In Experiment 2, we used bivalent stimuli for the weaker tasks (long phrases, colour naming) and univalent stimuli for the stronger tasks (short phrases, word reading). For the phrase production task, we should again replicate Sikora et al., because they also used bivalent stimuli for the long phrases and univalent for the short phrases. However, for the Stroop task, symmetrical or asymmetrical switch costs should be obtained depending on whether inhibition or enhancement is present. Asymmetrical costs should be obtained if word reading is inhibited on colour naming trials. However, if colour naming is enhanced rather than word reading inhibited on colour naming trials, then symmetrical costs should be obtained for Stroop.

## Experiment 1

### Method

#### Participants

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

#### Materials, procedure, and design

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

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

#### Analysis

Only trials with fluent, correct responses were included in the analysis of the RTs. For phrase production, mean RTs were calculated for short repeat, short switch, long repeat, and long switch trials. For Stroop, mean RTs were calculated for word repeat, word switch, colour repeat, and colour switch trials. Using classic statistics (centred around *p* values), repeated measures ANOVAs were conducted to test for main effects and interactions. The factors were task (short vs. long, or word vs. colour) and trial type (repeat vs. switch).

To quantify the strength of the statistical evidence (something that *p* values do not do), Bayesian statistical analyses were performed and Bayes factors are reported for the critical tests (e.g. Rouder, Morey, Verhagen, Swagman, & Wagenmakers, 2017; Wagenmakers et al., 2017). The Bayesian analyses were performed using JASP (Love et al., 2017). A Bayes factor quantifies the evidence that the data provide for one hypothesis versus another. For example, when the Bayes factor $BF_{10}$ equals 20, the data are 20 times more likely under $H_1$ than under $H_0$. Note that the subscript "10" in $BF_{10}$ indicates that the Bayes factor quantifies the evidence that the data provide for $H_1$ versus $H_0$, whereas the subscript "01" indicates the reverse (i.e. $BF_{10} = 1/BF_{01}$). Under a standard interpretation, a $BF_{10}$ of 3–10 indicates "substantial evidence", 10–30 "strong evidence", 30–100 "very strong evidence", and > 100 "decisive evidence" for $H_1$. We report the Bayesian results alongside those of the classic analyses with the idea that confidence in the results increases if both types of analyses support the same conclusions.

### Results and discussion

Figure 1 displays the RT results. The left panel shows the mean RTs in the switch and repeat conditions for the short and long phrase production tasks and the right panel shows the mean RTs for the Stroop reading and colour naming tasks. We followed the convention in the literature (e.g. Allport & Wylie, 1999, 2000; Yeung & Monsell, 2003) and our earlier work (Sikora, Roelofs, & Hermans, 2016; Sikora, Roelofs, Hermans et al., 2016) of plotting the RTs such that the two lines represent the two tasks and the categories along the horizontal represent the repeat and switch conditions (rather than the other way around, as was done by Schneider & Anderson, 2010). The figure shows that there are asymmetrical switch costs for both the phrase production and Stroop tasks, with the stronger tasks (i.e. producing short phrases, Stroop reading) exhibiting a larger switch cost than the weaker tasks (i.e. producing long phrases, Stroop colour naming).

For phrase production, the mean RT was shorter on repeat trials than on switch trials, $F(1, 15) = 36.67$, $MSE = 826$, $p < .01$, $\eta_p^2 = .71$, $BF_{10} = 200.73$. This Bayes factor indicates that the data are about 200 times more likely

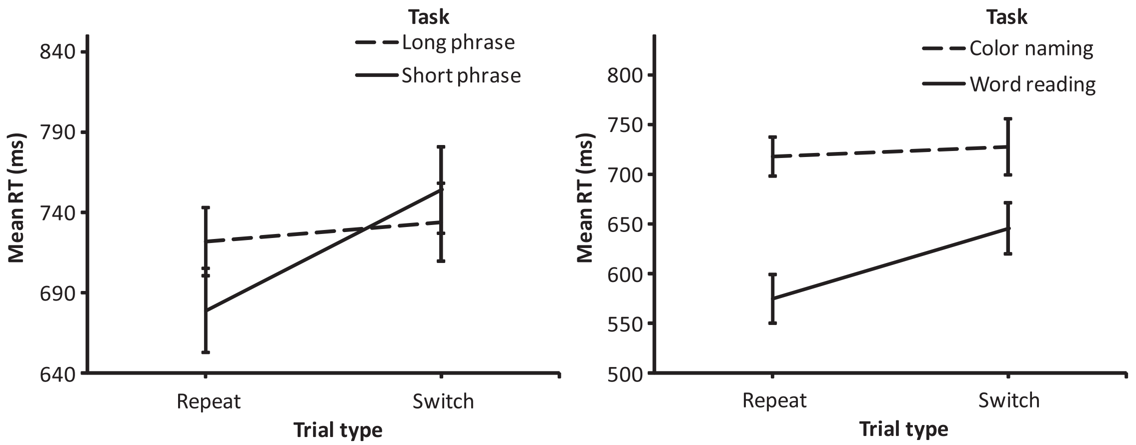


**Figure 1.** Mean response time (RT) for producing short and long noun-phrases (left panel) and Stroop colour naming and reading (right panel) on repeat and switch trials in Experiment 1. The error bars indicate one standard error.

under the $H_1$ that there is a switch cost than under the $H_0$ that there is no such effect. The RTs did not differ between short and long phrases, $F(1, 15) = 0.74$, $MSE = 2667$, $p = .40$, $\eta_p^2 = .05$, $BF_{10} = 0.40$. However, task and trial type interacted, $F(1, 15) = 26.46$, $MSE = 591$, $p < .001$, $\eta_p^2 = .64$, reflecting that the switch cost was larger for the short than for the long phrases (75 ms vs. 12 ms), $BF_{10} = 485.31$. In particular, a significant switch cost was obtained for the short phrases, $t = 8.0$, $p < .001$, $BF_{10} = 38939.83$, but not for the long phrases, $t = 1.30$, $p = .22$, $BF_{10} = 0.91$. The error percentages for the short repeat, short switch, long repeat, and long switch conditions were 4.8%, 7.3%, 13.0%, and 12.6%, respectively. The statistical analysis revealed a difference between the short and long phrases, $F(1, 15) = 38.64$, $MSE = .002$, $p < .001$, $\eta_p^2 = .72$, $BF_{10} = 765198.03$, but there was no difference between switch and repeat trials, $F(1, 15) = 1.04$, $MSE = .002$, $p = .32$, $\eta_p^2 = .07$, $BF_{10} = 0.32$. There was no interaction between task and trial type, $F(1, 15) = 3.37$, $MSE = .004$, $p = .09$, $\eta_p^2 = .18$, $BF_{10} = 0.89$.

In the Stroop task, mean RT was shorter on repeat trials than on switch trials, $F(1, 15) = 16.11$, $MSE = 1226$, $p < .001$, $\eta_p^2 = .52$, although the evidence for an overall switch cost was weak, $BF_{10} = 1.31$. Also, RTs were shorter for word reading than for colour naming, $F(1, 15) = 69.38$, $MSE = 2931$, $p < .001$, $\eta_p^2 = .82$, $BF_{10} = 7.62 \times 10^7$. Moreover, task and trial type interacted, $F(1, 15) = 8.65$, $MSE = 7001$, $p < .01$, $\eta_p^2 = .37$, reflecting that the switch cost was larger for reading than for colour naming (71 ms vs. 10 ms), $BF_{10} = 10.75$. A significant switch cost was obtained for word reading, $t = 5.20$, $p < .001$, $BF_{10} = 536.67$, but not for colour naming, $t = 0.63$, $p = .54$, $BF_{10} = 0.44$. The error percentages for the word repeat, word switch, colour repeat, and colour switch conditions were 1.8%, 3.1%, 3.8%, and 3.8%, respectively. The statistical analysis yielded no difference between word reading and colour naming, $F(1, 15) = 2.20$, $MSE = .001$, $p = .16$, $\eta_p^2 = .13$, $BF_{10} = 1.04$, and between switch and repeat trials, $F(1, 15) = 0.86$, $MSE = .001$, $p = .37$, $\eta_p^2 = .05$, $BF_{10} = 0.36$. There was no interaction between task and trial type, $F(1, 15) = 2.03$, $MSE = .001$, $p = .18$, $\eta_p^2 = .12$, $BF_{10} = 0.61$.

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

## Experiment 2

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

### *Method*

#### *Participants*

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

### *Procedure, materials, design, and analysis*

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

### *Results and discussion*

Figure 2 displays the RT results. The left panel shows the mean RTs in the switch and repeat conditions for the short and long phrase production tasks and the right panel shows the mean RTs for the Stroop reading and colour naming tasks. The figure shows that there are asymmetrical switch costs for the phrase production tasks but not for the Stroop tasks. In phrase production, the stronger task (i.e. producing short phrases) exhibits a larger switch cost than the weaker task (i.e. producing long phrases), as in Experiment 1. In the Stroop task, however, the switch cost does not seem to differ between the stronger and weaker tasks (i.e. Stroop reading and colour naming), different from Experiment 1.

For phrase production, the mean RT was shorter for the short phrases than for the long phrases, $F(1, 15) = 17.59$, $MSE = 6118$, $p < .001$, $\eta_p^2 = .54$, $BF_{10} = 192034.43$. Also, RTs were shorter on repeat trials than on switch trials, $F(1, 15) = 11.40$, $MSE = 648$, $p < .01$, $\eta_p^2 = .43$, although the evidence for an overall switch cost was weak, $BF_{10} = 0.48$. Moreover, there was an interaction between task and trial type, $F(1, 15) = 8.71$, $MSE = 422$, $p < .01$, $\eta_p^2 = .37$, reflecting that the switch cost was larger for the short phrases than for the long phrases (37 ms vs. 6 ms), $BF_{10} = 10.94$. In particular, a significant switch cost was obtained for the short phrases, $t = 4.45$, $p < .001$, $BF_{10} = 146.78$, but not for the long phrases, $t = 0.78$, $p = .45$, $BF_{10} = 0.51$. The error percentages for the short repeat, short switch, long repeat, and long switch conditions were 5.9%, 4.7%, 11.7%, and 11.5%, respectively. The statistical analysis revealed a difference between short and long phrases, $F(1, 15) = 110.52$, $MSE = .001$, $p < .001$, $\eta_p^2 = .88$, $BF_{10} = 2.41 \times 10^8$. The error percentages did not differ between switch and repeat trials, $F(1, 15) = 0.85$, $MSE = .001$, $p = .37$, $\eta_p^2 = .05$, $BF_{10} = 0.29$. There was no interaction between task and trial type, $F(1, 15) = 0.30$, $MSE = .005$, $p = .59$, $\eta_p^2 = .02$, $BF_{10} = 0.30$.

In the Stroop task, mean RT was shorter on repeat than on switch trials, $F(1, 15) = 36.03$, $MSE = 420$, $p < .001$, $\eta_p^2 = .71$, although the evidence for an overall switch cost was weak, $BF_{10} = 0.49$. Also, RTs were shorter for word reading than colour naming, $F(1, 15) = 81.78$, $MSE = 5243$, $p < .001$, $\eta_p^2 = .85$, $BF_{10} = 1.81 \times 10^{15}$. However, we did not obtain an interaction between task and trial type, $F(1, 15) = 0.73$, $MSE = 1297$, $p = .41$, $\eta_p^2 = .05$, $BF_{10} = 0.45$. Thus, there was now no significant switch cost asymmetry (i.e. the switch costs were 35 ms for reading and 27 ms for colour naming). The error percentages for the word repeat, word switch, colour repeat, and colour switch conditions were 1.4%, 1.0%, 4.4%, and 6.3%, respectively. The statistical analysis revealed a difference between word reading and colour naming, $F(1, 15) = 9.67$, $MSE = .003$, $p < .01$, $\eta_p^2 = .39$, $BF_{10} = 187.50$. The error percentages did not differ between switch and repeat trials, $F(1, 15) = 0.71$, $MSE = .001$, $p = .41$, $\eta_p^2 = .05$, $BF_{10} = 0.31$. There was no interaction between task and trial type, $F(1, 15) = 2.38$, $MSE = .003$, $p = .14$, $\eta_p^2 = .14$, $BF_{10} = 0.78$.

## Combined analysis of experiments 1 and 2

In the RTs, there was no switch cost for the long phrases in Experiments 1 and 2, whereas the short phrases showed a switch cost in both experiments. Numerically,

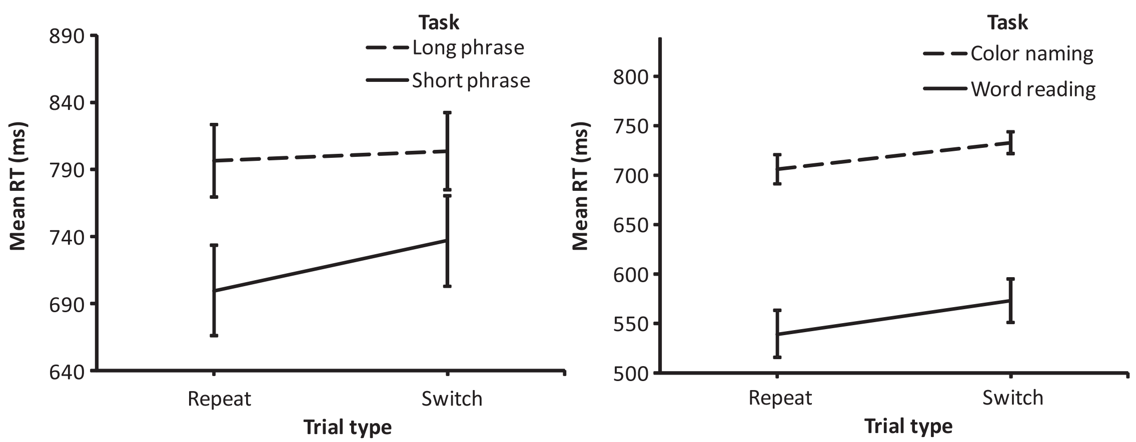


**Figure 2.** Mean response time (RT) for producing short and long noun-phrases (left panel) and Stroop colour naming and reading (right panel) on repeat and switch trials in Experiment 2. The error bars indicate one standard error.

this switch cost was larger in Experiment 1 than in Experiment 2. We examined whether the switch costs for the short phrases differed statistically between experiments by running a joint analysis of the experiments. We tested for a triple interaction of experiment (first, second), task (short, long), and trial type (repeat, switch). The statistical analysis showed that the overall switch cost was larger in Experiment 1 than in Experiment 2, $F(1,\ 30) = 5.26$, $MSE = 737$, $p < .001$, $\eta_p^2 = .15$. Moreover, there was a triple interaction of experiment, task, and trial type, $F(1,\ 30) = 4.10$, $MSE = 506$, $p < .05$, $\eta_p^2 = .12$. The switch cost on the short phrase trials was larger in Experiment 1 than in Experiment 2, $t = 3.05$, $p < .05$, $BF_{10} = 17.92$, whereas the switch costs for the long phrases in Experiments 1 and 2 did not differ, $BF_{10} = 0.37$. Recall that the previous Bayesian analyses indicated that the evidence for an interaction between task (short vs. long) and trial type (repeat vs. switch) was decisive in Experiment 1 and strong in Experiment 2, so the evidence suggests that there were asymmetrical switch costs in both experiments.

For the Stroop task RTs, a switch cost asymmetry was obtained in Experiment 1, but the switch costs were symmetrical in Experiment 2. To corroborate that the switch cost patterns differed between experiments, we ran a joint analysis of the experiments. In particular, we tested for a triple interaction of experiment (first, second), task (word reading, colour naming), and trial type (repeat, switch). The statistical analysis showed that the overall switch costs did not differ between Experiments 1 and 2, $F(1,\ 30) = 0.73$, $MSE = 1023$, $p = .40$, $\eta_p^2 = .02$. However, there was a triple interaction of experiment, task, and trial type, $F(1,\ 30) = 5.59$, $MSE = 1037$, $p < .05$, $\eta_p^2 = .16$. Further analysis revealed that the switch cost on the word reading trials was larger in Experiment 1 than in Experiment 2, $t = 2.42$, $p < .05$, $BF_{10} = 5.54$, but switch costs did not differ between experiments for colour naming, $t = 1.02$, $p = .32$, $BF_{10} = 0.50$. Recall that the previous Bayesian analyses indicated that the evidence for an interaction between task (reading vs. colour naming) and trial type (repeat vs. switch) was strong in Experiment 1 but absent in Experiment 2, so the evidence suggests that switch costs were asymmetrical in Experiment 1 but symmetrical in Experiment 2.

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

Additionally, we analyzed the switch costs as the percent increase in the RT from the repeat to the switch trials to make sure that the differential switch costs between the tasks did not arise due to differences in basic response speed. We found significantly greater proportional switch costs for the short phrases than for the long phrases in Experiment 1, $t = 5.33$, $p < .001$, and in Experiment 2, $t = 3.49$, $p < .01$. Moreover, we found significantly greater switch costs for word reading than for colour naming in Experiment 1, $t = 3.30$, $p < .01$, but not in Experiment 2, $t = 1.69$, $p = .11$. These findings confirm the outcomes of our earlier analyses and demonstrate that the differential switch costs between the tasks did not arise due to differences in response speed.

## General discussion

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

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

For the phrase production task, we obtained asymmetrical switch costs, both when we used bivalent stimuli (Experiment 1) and when we used univalent stimuli for the short phrases and bivalent stimuli for the long phrases (Experiment 2). This suggests that the switch cost asymmetry was due to inhibition. If the task set for short phrases is inhibited on long-phrase trials, then an asymmetrical switch cost should be obtained regardless of whether the stimuli for the short phrases are bivalent (Experiment 1) or univalent (Experiment 2), which corresponds to what we observed empirically.

However, as the combined analysis showed, the cost of switching to the short phrases was much larger in Experiment 1 than in Experiment 2 (i.e. 75 ms vs. 37 ms, respectively). This may suggest that the larger switch cost for the short phrases than the long phrases is not only due to inhibition of the task set for short phrases on long-phrase trials, but also to enhancement of the task set for long phrases on long-phrase trials. In switching to black-and-white pictures requiring a short phrase response (Experiment 2), only inhibition can play a role because a black-and-white picture does not afford a long phrase response. However, in switching to a coloured picture requiring a short phrase response (Experiment 1), not only inhibition but also enhancement can play a role, because a coloured picture affords a long phrase response. As a consequence, not only previous inhibition of the task set for short phrases but also previous enhancement of the task set for long phrases must be overcome, which may increase the switch cost. This would explain why the cost of switching to the short phrases was much larger in Experiment 1 than in Experiment 2. Alternatively, more inhibition may have been applied in Experiment 1 than Experiment 2. This difference may have occurred because short phrases were always produced in response to coloured pictures in Experiment 1 but never in Experiment 2, and therefore stronger inhibition of the task set for short phrases may have been required on long-phrase trials in Experiment 1.

The critical finding was that both task pairs produced asymmetrical switch costs in Experiment 1, whereas for Experiment 2 asymmetrical switch costs were observed for the noun phrase tasks and symmetrical switch costs for the Stroop tasks. From this, we concluded that different attentional mechanisms are at work. However, one may wonder whether the test was fair. When switching between noun phrases, no switch costs were observed for long noun phrases in either experiment. Thus, obtaining a symmetrical pattern would seem to imply that a switch cost for the short phrases should be abolished altogether. Note, however, that this is not necessarily the case. For the Stroop task in Experiment 1, a switch cost was present for reading but not for colour naming, yielding the asymmetry in switch costs. However, in Experiment 2, equal switch costs were present for reading and colour naming. Thus, changing the attentional control demands for one task (reading) may also effect performance in the other task (reading), as observed by Yeung and Monsell (2003). Thus, in principle, symmetrical switch costs for the short and long phrases may have been obtained in Experiment 2 even though there was no switch cost for the long phrases in Experiment 1.

We argued that black-and-white pictures do not afford a long phrase response. Still, one could argue that participants still could respond by saying “the white fork” (although white is not a colour in the experiment in the way the other colours are). However, if participants planned to say “the white fork” but suppressed “white” before articulation, then one would expect occasional errors in which they actually said “white”. However, such errors were not observed.

Our evidence that participants do not inhibit word reading in Stroop colour naming corresponds to behavioural and neuroimaging findings in the literature. It has been argued that inhibition is implemented by a neural circuitry consisting of the right inferior frontal gyrus, pre-supplementary motor area, and subthalamic nucleus (e.g. Aron, Behrens, Smith, Frank, & Poldrack, 2007; Van den Wildenberg et al., 2011). Meta-analyses of the neuroimaging literature on colour-word Stroop task performance have shown activation of areas such as the anterior cingulate cortex but not of the right inferior frontal gyrus (Laird et al., 2005; Nee, Wager, & Jonides, 2007; Neumann, Lohmann, Derrfuss, & Von Cramon, 2005), suggesting that inhibition is not engaged in the Stroop task. Moreover, inhibition has been associated with certain characteristics of the tail of RT distributions (Van den Wildenberg et al., 2011). Studies have shown that these characteristics are observed in performing several interference tasks but not in colour-word Stroop (Lamers et al., 2010; Pratte et al., 2010; Shao et al., 2015), also suggesting that inhibition is not engaged in the Stroop task. Thus, our evidence that participants do not inhibit word reading in Stroop colour naming is in line with extant behavioural and neuroimaging findings.

Unfortunately, based on the present experiments, we cannot say why a different attentional mechanism is engaged in switching between short and long noun-phrases (inhibition) than in switching between reading and colour naming (enhancement). Important for now, however, is that our experiments provide evidence that different attentional mechanisms are involved. Future research may further examine the exact reason why switching between short and long noun-phrases engages inhibition whereas switching between reading and colour naming does not.

Although it is often acknowledged that attention may operate through inhibition or enhancement depending on the tasks and experimental circumstances (cf. Pillsbury, 1908), theories of task switching have either emphasised a role for inhibition (Allport et al., 1994; Meuter & Allport, 1999) or they assume no role for inhibition (Bryck & Mayr, 2008; Schneider & Anderson, 2010; Yeung & Monsell, 2003). The outcomes of our study provide greater clarity on the issue of whether attentional inhibition, enhancement, or both are engaged. The results of our experiments show that inhibition or enhancement is engaged depending on the tasks and experimental circumstances. These results therefore challenge theories of task switching that assume only one attentional mechanism (i.e. Allport et al., 1994; Bryck & Mayr, 2008; Meuter & Allport, 1999; Schneider & Anderson, 2010; Yeung & Monsell, 2003).

Comprehensive theoretical (implemented) models of attentional control within language production are still lacking. The present experiments were conducted within the theoretical framework for attentional control in language production proposed by Shao, Roelofs, and Meyer (2012), Sikora, Roelofs, and Hermans (2016), and Sikora, Roelofs, Hermans et al. (2016). They proposed a role for attentional inhibiting, updating, and shifting, following the general theory about attentional control of Miyake et al. (2000). For a computationally implemented model of the role of attentional enhancement in word and phrase production, we refer to Roelofs (2003, 2006, 2008a, 2014), and for the role of enhancement, updating, and shifting, we refer to Roelofs (2007, 2008b) and Roelofs and Piai (2011). The results of the present experiments highlight the importance of including inhibition in accounts of the attentional control of phrase production, in line with the findings of Shao, Roelofs, Acheson, and Meyer (2014) and Shao et al. (2015) on single word production.

To conclude, we obtained evidence that switching to short phrases involves overcoming previous attentional inhibition of the task set for short phrases, and perhaps also overcoming previous enhancement of the task set for long phrases. In contrast, our findings suggest that switching to Stroop reading involves overcoming of enhancement of the task set for colour naming only. These findings further clarify how switch costs may be caused by task-set inertia and they demonstrate that switching between different tasks does not necessarily involve the same attentional mechanism, but which mechanism is engaged depends on the type of tasks involved. Thus, our findings challenge theories of task switching that assume only one attentional mechanism, inhibition or enhancement, rather than both mechanisms.

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No potential conflict of interest was reported by the authors.

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