The persisting influence of unattended auditory information: Negative priming in intentional auditory attention switching

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Abstract

We studied negative priming (NP) in auditory attention switching. In a cued variant of dichotic listening, two spoken number words were presented, one to each ear, one spoken by a female and one spoken by a male voice. A visual cue indicated whether the male or female voice was the target. A numerical magnitude judgement of the target number was required. The selection criterion could either switch or repeat across trials, so there were attention switch and repetition trials. Two experiments examined NP (distractor becomes target) and also included a "competitor priming" (CP) condition (target becomes distractor), relative to a "no priming" condition (target and distractor not related to previous trial). In Experiment 1, we investigated the basic priming effects. In Experiment 2, we additionally varied the response-cue interval (RCI; 100 ms vs. 1900 ms) to examine time-related changes in priming. We found longer response times (RT) for switch trials compared to repetition trials (attention switch costs), i.e., when the internal processing context changed. In addition, we found longer RT for NP trials as well as reduced switch costs in long RCI, suggesting that previously relevant attentional settings dissipate over longer time. However, NP was not influenced by attention switches and it was also not affected RCI. Hence, NP in auditory attention switching does not seem strongly context- or time-sensitive.

Keywords: attention switch; selective attention; negative priming; competitor priming; response-cue interval

Listening to only one person in a multi-talker situation is a common situation in everyday life. We are able to switch between different speakers and concentrate on the relevant one easily. This so-called “cocktail party” phenomenon was first investigated by Cherry (1953) using dichotic listening tasks. Two different streams of information were presented, one to each ear. Only one of them was task-relevant and was to be attended. It was shown that the relevant information can be processed quite well due to selective attention. Normally, the irrelevant information is suppressed but some of the information can also be perceived, like physical features. For example, participants remember when irrelevant speech changes into beeps or the gender of the irrelevant speaker changes (Cherry, 1953). These findings suggest that we are able to attend to relevant information, even though sometimes the irrelevant information is also processed to some degree, at least at a perceptual level.

According to the filter theory of attention (Broadbent, 1958), this is because processing is serial when it comes to semantic processing, creating a central bottleneck. Treisman (1964) suggested another theory, the attenuation theory. She assumed that all information is processed but the irrelevant information is only attenuated to some degree. Therefore, it is possible that unattended information could also be processed. However, involuntary attention switches to the irrelevant information may also explain some of these results (Lachter, Forster, & Ruthruff, 2004). The present study is focused on the process of auditory attention switching.

To investigate auditory attention switching, a paradigm combining the dichotic listening paradigm with the cued task switching paradigm (Meiran, 1996) was developed by Koch, Lawo, Fels, and Vorländer (2011). As in task-cueing paradigms, a cue indicates which task has to be performed, and the task could either repeat or switch. Switching between tasks normally results in longer reaction times (RT) and higher error rates for the switch trials compared to the repetition trials. This is called switch costs (e. g., Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010; Koch, Poljac, Müller, & Kiesel, 2018; Rogers & Monsell, 1995).

Koch and colleagues (2011) presented two different number words simultaneously to the participants, one to each ear. The number words were spoken by two different speakers, a male and a female speaker. A visual cue before stimulus onset indicated whether to attend to the male or to the female voice, and the participants had to judge the magnitude of the target number. Hence, the task remained the same, but the attentional selection criterion switched. Across several studies (Koch et al., 2011; Koch & Lawo, 2014; Lawo & Koch, 2012, 2014), the authors found robust auditory attention switch costs, showing that intentional changes in attention selection come with performance declines.

In the present study, we explored whether irrelevant information influences intentional attention switches by examining negative priming (NP) in the attention-switch paradigm. In a typical NP situation there is a sequence of prime and probe trials, each including at least two stimuli, a target (to be attended, and requiring a response) and a distractor (to be ignored). When in some sequences the distractor of the prime trial becomes the target of the probe trial, longer RTs and higher error rates relative to a no priming condition are usually found. NP means that the ignored stimulus of the previous trial interferes with the subsequent processing of the to-be-attended stimulus in the current trial (Tipper, 1985; see Fox, 1995; Frings, Schneider, & Fox, 2015, for reviews).

Only few studies investigated the influence of previously to be ignored information on the current performance in auditory selective attention. For example, in a study by Banks, Roberts, and Ciranni (1995), two words were presented dichotically, one in a male voice and the other in a female voice. The instruction in a given trial was, for example, to attend only to the female voice and repeat the words aloud. The mean RT was longer when the target word (female voice) was the distractor in the previous trial (where the male voice was the target voice). Other studies with auditory stimuli have reported similar results using digitized sounds (Mayr & Buchner, 2014; Mayr, Möller, & Buchner, 2011; Mayr, & Buchner, 2010).

There are different explanations for NP. Tipper (1985) proposed that distractor objects are inhibited during target selection. When a distractor becomes a target, the mental representation of this stimulus is inhibited because it was previously a distractor. This inhibition needs to be overcome before responding to the current target in the correct way, which takes time. Another explanation is based on episodic retrieval (Logan 1988; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). Logan's (1988) instance theory of automatization (extended to NP) postulates that the response to a target depends on memory retrieval of previous processing episodes. These episodes contain information about the correct response. In a NP situation, the current target has a "do-not-respond" association from the previous trial. The correct processing of the current target is now in conflict with the retrieved processes executed during the previous episode, causing interference (Neill & Valdes, 1992; Neill et al., 1992). This mismatch between the processing episodes causes a longer RT (Fox, 1995; D'Angelo, Thomson, Tipper, & Milliken, 2016; Frings et al., 2015, for a review). This mismatch can also be found in so called competitor priming (CP) trials. In these trials, the target in the prime trial becomes the distractor in the probe trial. In this case, the distractor is now connected to a "respond" association that needs to be suppressed. Hence, it also leads to a mismatch between the episodes and results in longer RTs (Allport & Wylie, 2000).

At this stage, it is still debated whether NP is caused by inhibition or by episodic conflict. Most recent models agree that NP is complex and consists of several underlying processes (Mayr & Buchner, 2007; Neill, 2007; Tipper, 2001), with an emerging view that both mechanisms (inhibition and episodic retrieval) likely contribute to the NP phenomenon (Frings et al., 2015).

In order to examine the processes underlying NP, Frings, Koch, and Moeller (2017) developed a paradigm designed to separate retrieval processes from other processes involved in action control. All (episodic) retrieval processes are connected to memory processes. Hence, it is assumed that the context of an episode might facilitate involuntary retrievals of other episodes with the same context. For example, attentional sets can influence episodic retrieval, thus the retrieval is modulated by changes in context (Hommel, Memelink, Zmigrod, & Colzato, 2014). Based on this assumption, Frings and collaborators (2017) developed a paradigm in which the task set remained the same but there where attentional shifts. Participants had to do an object categorization task. They used distractor-response binding as a specific manipulation of possible episodic interaction between previous and present items. A change in the selection criterion was considered to be a change in context, which should reduce episodic similarity from prime to probe and thus reduce involuntary retrieval of the earlier episode. They found reduced distractor-repetition-binding priming effects in trials in which the selection criterion changed.

To extend these findings, we manipulated changes in context by auditory attention switches, which we conceptualize as changed internal processing context, to study their influence on NP and CP. In this case, a switch in selection criterion (e.g., switch between the male and the female voice) would represent a change in processing context, whereas repeating the selection criterion (e.g., repeatedly attend to the male voice) would represent no change in the processing context. Hence, if NP is produced, in part, by episodic retrieval conflict, we expect reduced NP in attention switch trials due to the change in retrieval context.

Here, we report two experiments using a cued variant of attention switching (Koch et al., 2011) in which two number words were presented simultaneously, one to each ear. A visual cue indicated whether to attend to the male or the female voice. This selection criterion could either repeat or switch from one trial to another and the target or distractor word could repeat across trials. Based on previous work, we expected longer RTs and higher error rates in switch trials compared to repetition trials (attention switch costs), and we also expected NP and CP effects regarding the identity of the stimuli, that is, longer RTs and higher error rates in these conditions compared to a no priming condition. Specifically, we investigated if conflict mediated by involuntary episodic retrieval contributes to NP. If so, we would expect that a change in the attention selection criterion would reduce NP. Thus, NP effects should be smaller in attention switch trials than in repetition trials, due to the change in context. In Experiment 2 the same experimental setting was used. Additionally, we investigated the influence of different response-cue-interval (RCI) conditions on both attention switching and NP and CP in order to explore whether NP in auditory selective attention switching is a time-sensitive effect.

Experiment 1

Method

Participants. Twenty-four students from the RWTH Aachen University (18 female and 24 right handed) between 19 and 29 (*M* = 22; *SD* = 1.96) years of age were tested individually. They all had normal or corrected-to-normal visual and auditory abilities and gave informed consent.

Stimuli and task. A task cue indicated which voice had to be attended (male or female). The cue was either a male or a female pictogram (6.2° visual angle) in white on a black screen. The auditory stimuli were German number words (1-9, without 5), spoken by three different speakers per gender, every sound was about 700 ms long, and sounds were adjusted to have equal subjective loudness (as in Koch et al., 2011). The stimuli were delivered via headphones (Grundig VIA High Definition Audio) at an average intensity of about 60 dB(A), which is as loud as a normal conversation. Between the trials there was a white fixation cross (1.9° visual angle), presented in the center of a black screen (17 inch and 1280 x 1024 pixel). The instruction was written in white presented on a black screen which was approximately 60 cm from the participant's eyes. The auditory stimuli were dichotically presented by two voices, a male and female one, one to each ear.

The task was to indicate if the target number was smaller or larger than five by button press, with a left key for "smaller" ("c" key on a QWERTZ- keyboard) and a right key for "larger" ("m" key; which was spatially compatible with the mental number line). The experiment ran in E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

Procedure. Written instructions were presented on the screen and participants were asked to respond as quickly as possible while keeping errors to a minimum. Every trial started with a fixation cross in the center presented for 500 ms, followed by the visual cue (pictogram), which remained in view until the button press response. Five hundred and fifty ms following cue onset, the word stimuli were presented dichotically. The participants had up to 4000 ms after the target onset to respond by pressing a key. There was no feedback for the correct response, but a red word was presented for an incorrect or too slow response ("Fehler", the German word for "error," or "schneller," the German word for "faster"). These words lasted 500 ms.

Every combination of target and distractor was possible, and assigned to trials at random at run time. The side of target and distractor and the speaker were chosen randomly. In each block, there were 64 female-target trials and 64 male-target trials. There were 128 trials per block and 6 blocks plus one practice block (32 trials randomized). In sum, the experiment had 800 trials including practice trials. The number of NP and CP trials varied slightly for each participant due to randomization. In addition, an immediate target repetition (e.g., target was "four" in the previous trial and then "four" again), an immediate distractor repetition, and target distractor switch in a subsequent trial were possible due to the randomization (e.g., the target was "three" and the distractor was "seven" in the previous trial, then the target was "seven" and the distractor was "three" in the current trial; in these trials there was NP and CP). The target and distractor switch trials were removed from data analyses, see below. After trial exclusion for the analyses, the average number of NP trials per participant was 65, the average number of CP trials 65 and the average number of no priming trials was 439. Moreover, the number of attention switch trials per participant was 291 and the average number of attention repetition trials was 289.

Design. The independent variables were priming condition (NP vs. CP vs. no priming) and attention switch (switch vs. repetition). As NP and CP are not directly comparable, the RT data were submitted to two non-orthogonal analyses of variance (ANOVA). First, we calculated the negative priming contrasts with the independent variables attention switch (repetition vs. switch) and priming condition (NP vs. no priming). Second, we calculated the competitor priming contrasts with the independent variables attention switch (repetition vs. switch) and priming condition (CP vs. no priming). Note that we compared NP with the no priming condition as well as CP with the no priming condition, which we take as "unprimed" baseline condition. The dependent variables were response time (RT) and error rates.

Results

The 32 practice trials were excluded from analyses, along with the first trial of each block, all trials in which target and distractor were identical (12.5% of all trials), all trials following an error, and all RT exceeding the mean ± 3 *SD*s as well as RT faster than 100 ms ("outliers"; 1.8% of all trials), and all trials in which the target and distractor in the previous trial were exactly the same stimuli as in the current trial, which might produce positive priming. Moreover, we excluded trials in which target and distractor switched because these trials were both NP and CP and thus, confounded. Additionally, we also excluded the error trials for RT analyses. The remaining RTs were averaged for each condition of priming and attention-switch conditions, for each participant.

Negative priming contrast. For the RT data, the ANOVA including NP versus no priming, and attention switching, showed a significant main effect of attention switch, $F(1, 23) = 32.706$, $p < .001$, $\eta_p^2 = .587$, indicating longer RT in switch than in repetition trials (1095 ms vs. 1047 ms), and thus 48 ms switch costs. The main effect of priming condition yielded a non-significant trend, indicating higher RT in NP trials compared to no priming trials (1080 ms vs. 1062 ms), $F(1, 23) = 4.174$, $p = .053$, $\eta_p^2 = .154$, showing a performance disadvantage of 18 ms for the NP condition. Importantly, the interaction between the conditions attention switch and priming condition was not significant, $F < 1$.

For the error rates, the companion ANOVA yielded a significant main effect of attention switch, $F(1, 23) = 4.401$, $p = .047$, $\eta_p^2 = .161$, indicating higher error rates in switch trials compared to repetition trials (7.0% vs. 5.7%). Like for the RT results, performance was worse in the NP condition than in the no priming condition (7.0% vs. 5.8%), but the main effect of priming condition was, again, just not significant, $F(1, 23) = 2.785$, $p = .109$, $\eta_p^2 = .108$. The interaction was not significant, $F < 1$.

Competitor priming contrast. For the RT data the ANOVA including CP and no priming and task switching also showed a significant main effect of attention switch, $F(1, 23) = 22.840$, $p < .001$, $\eta_p^2 = .498$, indicating longer RT in switch trials than in repetition trials (1084 ms vs. 1034 ms), so there were 50 ms switch costs. The ANOVA yielded neither a significant main effect of priming condition, with no significant difference between CP and no priming (1055 ms vs. 1062 ms), nor a significant interaction, *F*s < 1.

For the error rates, the main effect of attention switch was not significant, $F(1, 23) = 4.184$, $p = .052$, $\eta_p^2 = .154$, but indicated a trend for higher error rates in switch trials compared to repetition trials (6.5% vs. 5.3%). There was neither a significant main effect of priming condition with no significant difference between CP and no priming (6.0% vs. 5.8%), nor a significant interaction, Fs < 1.

Combined Analysis of RT and Error Rates: Inverse Efficiency Scores.

Negative priming contrast. In addition to the previous analyses that considered RTs and errors separately, we also calculated inverse efficiency scores that combined RT and accuracy into a single composite score (RT/pc, where pc is the proportion correct, or RT/(1 - pe), where pe the proportion of errors, Bruyer & Brysbaert, 2011, Vandierendonck, 2017; see also Liesefeld & Janczyk, 2019 for a discussion). A larger score indicates a lower efficiency (hence the designation of 'inverse-efficiency' score). For Experiment, 1 we found a lower efficiency for attention switch trials compared to repetition trials (1181 ms/pc vs. 1112 ms/pc), $F(1, 23) = 30.183$, $p < .0001$, $\eta_p^2 = .568$. We also found lower efficiency for NP trials compared with no-priming trials (1166 ms/pc vs. 1127 ms/pc), $F(1, 23) = 7.354$, $p = .012$, $\eta_p^2 = .242$. The interaction was not significant, $F < 1$.

In addition, to quantify the amount of evidence for the null result of the interaction and to quantify the amount of evidence for the alternative hypothesis in the main effects, we conducted a Bayesian analysis, more precisely we calculated a Bayes factor. More precisely, we calculated the $BF_{10,}$ which indicates the evidence in favor of the alternative hypothesis over the evidence for the null hypothesis. Here, we refer to the convention naming BF_{10} with values between 1 and 3 as anecdotal evidence for the alternative hypothesis, a BF_{10} value between 3 and 10 as moderate evidence and a BF_{10} between 10 and 30 as strong evidence for the alternative as strong evidence, whereas a BF_{10} over 100 extreme evidence for the alternative hypothesis is. Consequently, values between 1/3 and 1 are anecdotal evidence in favor of the null hypothesis, values between 1/10 and 1/3 are moderate evidence and values between 1/30 ad 1/10 are strong evidence for the null hypothesis (for a more detailed discussion see Wetzels et al., 2011).

The main effect of attention switch was supported by the Bayes factor, revealing extreme evidence for the alternative hypothesis, BF_{10} = 3774. The main effect of NP was also supported by moderate evidence for the alternative hypothesis, BF_{10} = 6.314. The calculated Bayes factor for this interaction revealed anecdotal evidence for the null hypothesis, BF_{10} = 0.420.

Competitor priming contrast. For the CP contrast in Experiment 1, we found a lower efficiency score in switch than in repetition trials (1159 ms/pc vs. 1091/pc), $F(1, 23) = 23.593$, $p < .0001$, $\eta_p^2 = .506$. We did not find a significant main effect of priming, $F < 1$, nor a significant interaction, $F(1, 23) = 1.188$, $p = 0.287$. As in the NP contrast, to quantify the amount of evidence for the null results and to quantify the amount of evidence for the alternative hypothesis in the main effects, we conducted a Bayesian analysis, more precisely we calculated the Bayes factor. The main effect of attention switch was supported by the Bayes factor, revealing extreme evidence for the alternative hypothesis, BF_{10} = 3614. The null effect of CP was also supported by moderate evidence for the null hypothesis, BF_{10} = 0.227. The calculated Bayes factor for this interaction revealed anecdotal evidence for the null hypothesis, BF_{10} = 0. 436.

Discussion

The switch costs observed in this experiment replicated several other studies using this paradigm (e.g., Koch et al., 2011; Koch & Lawo, 2014; Lawo & Koch, 2012, 2014). These switch costs indicate that intentional auditory attention switches produce additional interference between attending to the relevant information and ignoring the irrelevant information that was relevant in the trial before. We also found a trend of a NP disadvantage which was supported by significantly lower efficiency for NP, but this was not affected by attention switching. We did not find any evidence for CP.

Experiment 2

In Experiment 2, we re-examined NP and CP in the context of auditory attention switches, but we also varied the RCI to see if decreasing or increasing the temporal intervals across trials affects NP and CP.

Interestingly, Banks and colleagues (1995) found that NP with auditory stimuli observed with a short inter-trial interval (ITI) can become positive priming (shorter RT) when the ITI is longer. To examine temporal sensitivity, we varied the RCI between 100 ms and 1900 ms. For (attention) switch costs, several studies suggest a passive temporal dissipation of task sets for long RCI (Altmann, 2005; Meiran, Chorev, & Sapir, 2000). In random RCI, in the interval between response and upcoming cue, the task (or attention focus) of the next trial is not known yet. Previous studies found reduced switch costs shown for long RCI which might reflect passive dissipation or changes in temporal distinctiveness of preceding task episodes (see Horoufchin, Philipp, & Koch, 2011, for a discussion).

However, Koch and Lawo (2014) did not find a clear influence of the duration of RCI on auditory switch costs when they varied the RCI in blocks of short (100 ms) and long (1000 ms) RCI. In the present study, we almost doubled the duration of the long RCI (from 1000 ms to 1900 ms) to examine whether a much longer RCI would affect auditory attention switch costs. Importantly, we also examined whether NP and CP are dependent on RCI. Hence, in this experiment we were mostly interested to see whether auditory priming effects in attention switching are time-sensitive and whether this would be more strongly the case for attention repetition trials that resemble more the conditions examined by Banks et al. (1995).

Method

Participants. Twenty-four new students from RWTH Aachen University (22 female and 19 right handed) between 17 and 28 (*M* = 20.95; *SD* = 3.04) years of age were tested individually. They all had normal or corrected-to-normal visual and auditory abilities and gave written informed consent.

Stimuli, procedure, and design. Experiment 2 was like Experiment 1 except for the following differences. The RCI varied randomly between 100 ms and 1900 ms and the cue-stimulus-interval was 100 ms, whereas the cue stayed on the screen until the response was given. The experiment consisted of 9 blocks of 128 trials preceded by one practice block of 32 trials, hence 1184 trials in total including practice trials. The independent variables were as in Experiment 1, priming conditions (NP vs. CP vs. no priming) and attention switch (switch vs. repetition). In addition, we manipulated the RCI (100 ms vs. 1900 ms). In the analyses, we again calculated two non-orthogonal contrasts, comparing NP with the no priming condition and CP with the same no priming condition. The dependent variables were reaction time (RT) and error rates. After trial exclusion for the analyses, the average number of NP trials per participant was 91, the average number of CP trials 93 and the average number of no priming trials was 609. The number of attention switch trials per participant was 415 and the average number of attention repetition trials was 418. The average number of short RCI was 419 and the average number of long RCI was 415 per participant.

Results

The data were analyzed using the same exclusion criteria as in Experiment 1. Outlier rejection resulted in the loss of 1.7% of the data. Additionally, we excluded the error trials from RT analyses. The mean RTs and error rates are shown in Figures 1 and 2.

<Figure 1>

<Figure 2>

Negative priming contrast. The ANOVA including switch conditions and comparing NP and no priming for RT yielded a significant main effect of attention switch, $F(1, 23) = 33.521$, $p < .001$, $\eta_p^2 = .593$, indicating longer mean RT in switch trials than repetition trials (1132 ms vs. 966 ms), producing 166 ms switch costs. The main effect of priming was significant, $F(1, 23) = 11.142$, $p = .003$, $\eta_p^2 = .326$, showing longer RT for NP compared with no priming (1010 ms vs. 988 ms). This disadvantage of 22 ms for the NP condition confirmed the trend found in Experiment 1 (18 ms, $p = .053$). See also the section on inverse efficiency scores in the following.

There was a main effect of RCI, $F(1, 23) = 4.280$, $p = .050$, $\eta_p^2 = .157$, indicating that the mean RT was longer in the long-RCI condition than in the short-RCI condition (1018 ms vs. 980 ms), showing a disadvantage of 38 ms for the long RCI. However, this main effect was qualified by a significant interaction with attention switch, $F(1,23) = 22.894$, $p < .0001$, $\eta_p^2 = .499$. Post-hoc *t*-tests showed switch costs in the short RCI, $t(1, 23) = 8.933$, $p < .001$, as well as in the long RCI, $t(1, 23) = 4.797$, $p < .001$.

RCI did not interact significantly with priming condition, $F < 1$. The three-way interaction was not significant, $F(1, 23) = 1.004$, $p = .327$, $\eta_p^2 = .042$, as were all other interactions, *F*s < 1.

Error rates were analyzed with the same ANOVA as for RTs. We found higher error rates in switch trials than in repetition trials (9.9% vs. 7.8%), $F(1, 23) = 10.107$, $p = .004$, η_p^2

= .305. The error rate in NP condition was somewhat higher than that in the no priming condition (9.2% vs. 8.6%), but the main effect for NP was not significant, $F < 1$. The main effect of RCI was not significant, $F(1, 23) = 1.803$, $p = .192$, $\eta_p^2 = .073$, showing no difference in the mean accuracy in the short RCI compared to the long RCI (8.2% vs. 9.6%). No other interaction was significant, all *F*s < 1.

<Figure 3>

<Figure 4>

Competitor priming contrast. The mean RTs and error rates are shown in Figures 3 and 4. The ANOVA comparing CP and no priming in the RT data yielded a significant main effect of attention switch, $F(1, 23) = 75.079$, $p < .00001$, $\eta_p^2 = .765$, indicating longer RT in switch than in repetition trials (1013 ms vs. 953 ms), so there were 60 ms switch costs. The main effect of priming condition was not significant, $F(1, 23) = 3.749$, $p = .065$, $\eta_p^2 = .140$, but there was a trend indicating longer RT for no priming compared to CP (988 ms vs. 978 ms), suggesting a possible advantage of 10 ms for the CP condition.

The main effect of RCI was significant, $F(1,23) = 5.710$, $p = .025$, $\eta_p^2 = .199$, indicating generally longer RT for the long RCI compared to the short RCI (1005 ms vs. 961 ms), showing a disadvantage of 44 ms for the long RCI. However, this main effect was qualified in a significant interaction with attention switch, $F(1,23) = 15.643$, $p < .001$, $\eta_p^2 = .405$. For attention switch trials there was only little influence of RCI, 14 ms, which was not significant in a post-hoc *t*-test, $t(23) = -.859$, $p = .399$. However, for attention repetition trials, RT increased with long RCI relative to short RCI, 62 ms, which was significant in a post-hoc *t*-test, $t(23) = -3.454$, $p = .002$. As a consequence, attention switch costs were smaller in the long RCI compared to the short RCI (36 ms vs. 84 ms). There was neither a significant interaction between priming and RCI, $F(1,23) = 1.644$, $p = .212$, $\eta_p^2 = .067$, nor an interaction between attention switch, priming, and RCI, $F(1, 23) = 1.456$, $p = .240$, $\eta_p^2 = .060$. The ANOVA yielded no significant interaction between priming and attention switch, $F < 1$.

The ANOVA for error rates yielded a significant main effect of priming, $F(1, 23) = 7.229$, $p = .013$, $\eta_p^2 = .239$, indicating higher error rates in no priming than in CP trials (8.6% vs. 6.8%). This data pattern supports the non-significant trend in RT (10 ms, $p = .065$), showing that the CP condition seems to produce an advantage in speed and accuracy. There was no significant main effect of attention switch, $F < 1$, and no significant main effect of RCI, $F(1, 23) = 1.148$, $p = .295$, $\eta_p^2 = .048$.

The interaction between CP and attention switch was significant, $F(1, 23) = 14.795$, $p < .001$, $\eta_p^2 = .391$. No other interaction was significant, *F*s < 1. Post-hoc *t*-tests for the interaction between CP and attention switch showed, surprisingly, a CP advantage primarily in switch trials, $t(23) = -5.988$, $p < .0001$, but not in repetition trials, $t(23) = .743$, $p = .465$ (4.4% vs. -0.9%). Put differently, for the error rates in the CP condition, there was a clear advantage of attention switches (i.e., a switch benefit). This contrasts with the RT data, which show a clear disadvantage of attention switches (i.e., a switch cost). At this stage, it seems difficult to explain this particular apparent speed-accuracy trade-off, and we also note that it was not present in Experiment 1 (with an intermediate RCI). Therefore, we rather assume, for the time being, that the peculiar interaction observed in the error rates of Experiment 2 might reflect a spurious finding (possibly a “false positive”), so that we prefer to interpret this finding carefully until it is backed up by further empirical evidence.

Combined Analysis of RT and Error Rates: Inverse Efficiency Scores.

Negative priming contrast. As for Experiment 1, we computed inverse efficiency scores by dividing RT by the proportion correct, for each condition for each subject. In the negative priming contrast, processing was less efficient (higher RT/pc score) in attention switch trials compared to repetition trails (1153 ms/pc vs. 1051 ms/pc), $F(1, 23) = 33.012$, $p < .001$, $\eta_p^2 = .589$. Efficiency was also lower in NP trials than in no-priming trials (1121 ms/pc vs. 1084 ms/pc), $F(1, 23) = 11.246$, $p = .003$, $\eta_p^2 = .328$. In short RCI, efficiency was higher than in long RCI (1075ms/pc vs. 1130 ms/pc), $F(1, 23) = 5.623$, $p = .026$, $\eta_p^2 = .196$. As well as in RT data, the interaction between attention switch and RCI revealed a significant effect, $F(1, 23) = 11.131$, $p = .003$, $\eta_p^2 = .330$, indicating higher switch costs and hence lower efficiency in short RCI compared to long RCI (82 ms/pc vs. 39 ms/pc). Neither the interaction between priming and RCI nor the interaction between priming and attention switch were significant, *F*s < 1. The three-way interaction was also not significant, $F(1, 23) = 1.266$, $p = .272$, $\eta_p^2 = .052$.

As in Experiment 1, we calculated the Bayes factor for the main effects and the interactions in order to quantify the amount of evidence for the null hypothesis. The Bayes factor for the main effect of attention switch revealed extreme evidence for the alternative hypothesis, $BF_{10} = 4.128*e^6$, the Bayes factor for the main effect of NP revealed anecdotal evidence for the alternative hypothesis, $BF_{10} = 1.747$, and the Bayes factor for the main effect of RCI revealed very strong evidence for the alternative hypothesis, $BF_{10} = 36.548$. The Bayes factor for the interaction between attention switch and RCI revealed moderate evidence for the alternative hypothesis, $BF_{10} = 3.732$. The Bayes factor for the interaction between NP and RCI revealed moderate evidence for the null hypothesis, $BF_{10} = 0.214$. The Bayes factor for the interaction between attention switch and NP revealed moderate evidence for the null hypothesis, $BF_{10} = 0.235$. The Bayes factor for the three-way interaction revealed anecdotal evidence for the null hypothesis, $BF_{10} = 0.405$.

Competitor priming contrast. For the competitor priming contrast in Experiment 2, we found lower efficiency (higher scores) in switch trials compared to repetition trials (1101 ms/pc vs. 1036 ms/pc), $F(1, 23) = 29.689$, $p < .0001$, $\eta_p^2 = .563$. Moreover, we found a significant main effect of priming, $F(1, 23) = 7.161$, $p = .013$, $\eta_p^2 = .237$, indicating higher scores for the no priming condition compared to the CP condition (1084 ms/pc vs. 1053 ms/pc). We also found a significant main effect of RCI, $F(1, 23) = 7.392$, $p = .012$, $\eta_p^2 = .243$ indicating higher scores for long RCI compared to short RCI (1096 ms/pc vs. 1040 ms/pc). The interaction between attention switch and RCI was significant, $F(1, 23) = 4.701$, $p = .041$, $\eta_p^2 = .170$, indicating higher switch costs and hence lower efficiency in short RCI compared to long RCI (72 ms/pc vs. 39 ms/pc). The interaction between attention switch and priming was significant, $F(1, 23) = 8.643$, $p = .007$, $\eta_p^2 = .273$, indicating no effect of CP in repetition trials (0 ms/pc) but a CP advantage of 63 ms/pc in the switch trials. The interaction between priming and RCI was not significant, $F < 1$, neither was the three-way interaction, $F(1, 23) = 2.235$, $p = .149$, $\eta_p^2 = .089$.

As in Experiment 1, we calculated the Bayes factor for the main effects and the interactions in order to quantify the amount of evidence for the null hypothesis. The Bayes factor for the main effect of attention switch revealed extreme evidence for the alternative hypothesis, $BF_{10} = 53785$, the Bayes factor for the main effect of CP revealed moderate evidence for the alternative hypothesis, $BF_{10} = 3.687$, and the Bayes factor for the main effect of RCI revealed extreme evidence for the alternative hypothesis, $BF_{10} = 2256$. The Bayes factor for the interaction between attention switch and RCI revealed anecdotal evidence for the null hypothesis, $BF_{10} = 0.544$. The Bayes factor for the interaction between priming and RCI revealed moderate evidence for the null hypothesis, $BF_{10} = 0.220$. The Bayes factor for the interaction between attention switch and CP revealed substantial evidence for the alternative hypothesis, $BF_{10} = 5.363$. The Bayes factor for the three-way interaction revealed anecdotal evidence for the null hypothesis, $BF_{10} = 0.508$.

Discussion

In line with the trend in Experiment 1, we found a NP effect, that is, performance disadvantage for NP trials which was supported by follow-up analyses. Notably, in Experiment 2 we found a CP advantage that we did not observe in Experiment 1. We also found an effect of RCI, showing that a long RCI increased RT primarily in attention repetition trials. However, the RCI variation had no influence on NP or CP.

General Discussion

In this study, we investigated NP and CP in an auditory attention switch situation with spoken auditory stimuli. The goal was to examine whether the underlying processes in NP are influenced by auditory attention switches. To this end, we used an auditory attention switch paradigm with both targets and distractors and compared NP and CP with a no priming condition. In a second experiment we varied the RCI to explore temporal dependencies of NP and CP, as well as the temporal dissipation of attention switch costs.

We found attention switch costs in both experiments and a performance disadvantage for the NP condition in RT data. Additionally, we found an RCI effect, showing increased RT with longer RCI. However, we found reduced switch costs for the long RCI compared to the short RCI. We did not find a clear influence of attention switches on NP effects, and we found a small CP advantage only in Experiment 2. There was no influence of RCI on the different priming conditions.

NP and CP in auditory attention switching

We found robust attention switch costs across experiments. This is in line with findings of several other studies using this paradigm and shows limitations in intentional attention switching (Koch et al., 2011; Koch & Lawo, 2014; Lawo & Koch, 2014).

Note that we found a CP advantage only in Experiment 2. This finding suggests a facilitation of target processing if the distractor has been processed just before because it was primed by having been the previous target. Possibly, this CP benefit suggests that the distractor is processed more quickly and can thus be excluded faster from further processing, resulting in generally slightly improved performance (see also Nolden, Ibrahim, & Koch, 2019). However, because we did not find any evidence for such CP in Experiment 1, we will not further discuss this finding here.

More importantly, in both experiments we found evidence for NP, in terms of a performance disadvantage, in both RT data and error rates (corroborated by the analyses of inverse-efficiency scores), and this NP effect was statistically equivalent in attention repetitions and switches.[1] Note that in this experimental design, attention switching led to a switch in the gender of the target voice. Thus, in switch trials, distractor gender and target gender swapped from prime to probe trial. This confound might have also influenced the CP advantage discussed above, as the target speaker in the prime and the distractor speaker in the probe trial shared physical similarities. However, we used 3 different speakers per gender, so that there was some variance of speaker identity within the same speaker category (female or male). In a supplementary analysis, we focused on attention switch trials only in order to check for physical similarities of distractor speaker in trial n-1 and target speaker in trial n. We compared CP for digit repetitions with the exact same speaker with digit repetitions with a different speaker of the same gender. We found no modulation of priming effects when the digit and the voice of the speaker repeated compared to trials in which the digit repeated but the voice switched[2].

[1] Note that we also analyzed the influence of congruency of the current trial in a post-hoc analysis. Except for a small effect in the error rates in Experiment 1, which showed a negative priming effect only in the current incongruent trials, $F(1, 23) = 4.979$, $p = .036$, we did not find any influence of the congruency of the stimuli on NP, all $p > .142$.

[2] We only used CP switch trials in which the target digit (n-1) became distractor digit (n) and compared trials in which the speaker was the exact same in these two trials compared to trials in which the speaker switched. In Experiment 2, a paired *t*-test did not show an advantage for exact physical similarity in the RT data, $t(1, 23) = .961$, $p = .346$. For the error rates, a paired *t*-test revealed no significant difference between the error rates in the speaker repetition and the speaker switch condition, $t(1, 23) = .000$, $p > 0.99$

Therefore, the NP effect can be explained by mechanisms postulated in several accounts of NP, such as persisting inhibition or episodic retrieval. The persisting inhibition view assumes that inhibition of the ignored distractor in a previous trial persists and impairs directing attention to this stimulus as a target in the current trial (Tipper, 1985). On the episodic retrieval view, it is assumed that an episodic representation of a previous distractor response might be retrieved when this stimulus occurs again as a target. Mayr and Buchner (2006) extended the episodic retrieval view, suggesting that NP can also be caused by the retrieval of the prime response in stimulus repetition trials rather than the retrieval of a 'do not respond' tag for the distractor. If this was true, we should find (larger) NP effects in response switch trials in which the response in the current trial mismatches the response of the previous trial. Note, however, that we did not find any influence of the response transition on NP effects in Experiment 1 and Experiment 2[3]. Either way, most recent models suggest to us that NP likely involves a mixture of inhibition and retrieval processes (Frings et al., 2015). Importantly, to our knowledge, this is the first study showing NP with spoken material in auditory attention switching.

Interestingly, we found no influence of attention switches on NP. On the episodic retrieval account, one would have expected a reduction in NP on attention switch trials because the switch in auditory context should reduce the degree of match with previous episodes (Frings et al., 2017). These assumptions were not supported by our results.

Moreover, we also did not observe a modulation of NP effects by the duration of the RCI. A decreased NP effect in long RCI trials would support the inhibition view as well as

[3] In Experiment 1, the NP effect (NP – no priming) was 10 ms (1072 ms vs. 1062 ms) in the response repetitions and 30 ms (1092 ms vs. 1062 ms) in the response switch trials. But again, the ANOVA revealed no significant interaction between NP and response transition, $F(1, 23) = 2.267$, $p = .146$. In Experiment 2, the NP effect was 28 ms (1020 ms vs. 992 ms) in the response repetition trials and 9 ms (993 vs. 984) in the response switch trials, but again the ANOVA revealed no significant interaction between NP and response transition, $F(1, 23) = 1.675$, $p = .208$.

the episodic retrieval view. On the one hand, inhibition processes are modulated by temporal processes and decay over time. Hence, the inhibition related to the prime distractor should decay with long RCI and therefore reduce NP effects in long RCI. On the other hand, retrieval processes are memory processes. Thus, a long RCI would also represent a longer retention interval. In the memory literature, a long retention interval results in lower memory performance due to forgetting (Baddeley, Eysenck, & Anderson, 2014). Therefore, in long RCI the previous episode might be less likely retrieved. Reduced NP effects should be observed with these long RCIs as the previous episode has less influence on current target processing.

Note that in our experiment the RCI changed on a trial-by-trial basis. According to the episodic retrieval account, NP depends on the RCI before the episode of the prime (episode n-1) and the RCI before the episode of the probe (episode n, see Neill, Valdes, Terry, & Gorfein, 1992). Specifically, one would expect smallest NP effects in trials in which the previous RCI was short and the current RCI is long. In this case, the episode before the prime episode (episode n-2) competes with the prime episode (episode n-1) because of the short RCI between these episodes. In combination with the current long RCI between the prime and the probe episode, the prime episode should be less likely to be retrieved in the probe episode. Moreover, one would expect largest NP effects in trials where the previous RCI was long and the current RCI is short. In this case, the long RCI between the episode before the prime episode (episode n-2) and the prime episode itself (episode n-1) leads to no competition between these episodes. Combined with the short RCI between prime and probe, this leads to a more probable retrieval of the prime episode in the probe episode and hence to more NP in these trials. On the other hand, the inhibition account would predict larger NP on short RCI trials but no influence of the previous RCI on NP. However, we ran post-hoc analyses testing this hypothesis and did not find any influence of the previous and current RCI combination on NP [4].

In Experiment 2 we were mostly interested to see whether auditory priming effects in attention switching are time-sensitive at all and whether this would be more strongly the case for attention repetition trials, but we did not observe any modulation of NP effects by the duration of the RCI. Hence, NP does not seem to be affected by temporal modulation on this short scale, at least under these experimental conditions.

However, both findings (no influence of attention switching on NP and no influence of RCI on NP) represent null-effects. Note, we had to exclude many trials due to trial randomization, which likely reduced our power to detect small effects. Moreover, our sample sizes were probably not large enough to detect smaller effects with sufficient power, so that we need to be cautious not to overstate the theoretical conclusions from these particular null effects.

Temporal dissipation of auditory attention settings

We found decreased attention switch costs in long RCI trials and longer RTs for the long RCI condition, which was primarily observed in attention repetition trials. Note, that the Bayes factor for this interaction in the CP contrast remained inconclusive (anecdotal evidence for the null hypothesis). However, all other analyses revealed an influence of RCI manipulation in attention switch costs including the calculated Bayes factors.

Generally, increased RT, for the long RCI condition might be due to an increase in temporal uncertainty for the upcoming cue onset, which would have slowed cue processing. The findings regarding reduced switch costs extended the results of Koch and Lawo (2014)

[4] We ran an ANOVA with the variables priming, RCI and RCI N-1. The ANOVA revealed no significant interaction between any of the variables, all *F*s < 1.

who manipulated RCI across a much smaller scale (100 ms vs. 1000 ms instead of 100 ms vs. 1900 ms in the present study). They did not find an influence of RCI on auditory attention switch costs. Note, however, that they used a blocked RCI manipulation, whereas we manipulated RCI across trials. Also, our long RCI was almost doubled compared to the long RCI used in their study, so that the difference in the pattern of RCI effects across the present Experiment 2 and the two experiments reported by Koch and Lawo (2014) may suggest that dissipation of auditory attention sets requires a delay longer than Koch and Lawo's (2014) study.

Finding reduced switch costs in long RCI trials was explained in studies using task switching methodology as a decay of the activation of task set features. As the upcoming cue is not known yet, these findings cannot be explained by an active preparation (Altmann, 2005; Meiran, Chorev, & Sapir, 2000; Koch & Allport, 2006). Notably, Horoufchin, Philipp, and Koch (2011) suggested a loss of repetition benefit in long RCI. The temporal distinctiveness of a task episode might be affected by a random variation of the RCI (Grange, 2016). Hence, the retrieval probability of this episode is influenced. At this stage the major finding of Experiment 2 is primarily that both NP and CP do not seem to be affected very strongly, if at all, by rather substantial variations of RCI, which still led to effects on auditory switch costs. Hence, this partial dissociation of RCI effects on attention switch costs and NP might suggest that the latter effects do not rely on the same mechanisms. Please note that the switch costs were much larger than the NP effects, so that further empirical evidence is needed to better understand the underlying mechanisms.

Conclusion

The present study demonstrated for the first time NP in auditory selective attention switching with spoken material. Attention switching also resulted in switch costs, replicating previous findings in similar studies, and these costs dissipated across very long time intervals (RCI), thus extending our knowledge from a previous study (Koch & Lawo, 2014) that employed a shorter RCI variation and that did not find dissipation of switch costs. Notably, NP was not affected by long RCI and also not by attention switches, which might suggest different underlying mechanisms for NP and attention switch costs. Follow-up research would need to clarify the mechanisms underlying NP and attention switching.

Open practices statement

None of the data for the experiments reported here is available, and none of the experiments was preregistered. Analyses scripts can be found on https://osf.io/qzxg8/.

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Tables and Figures

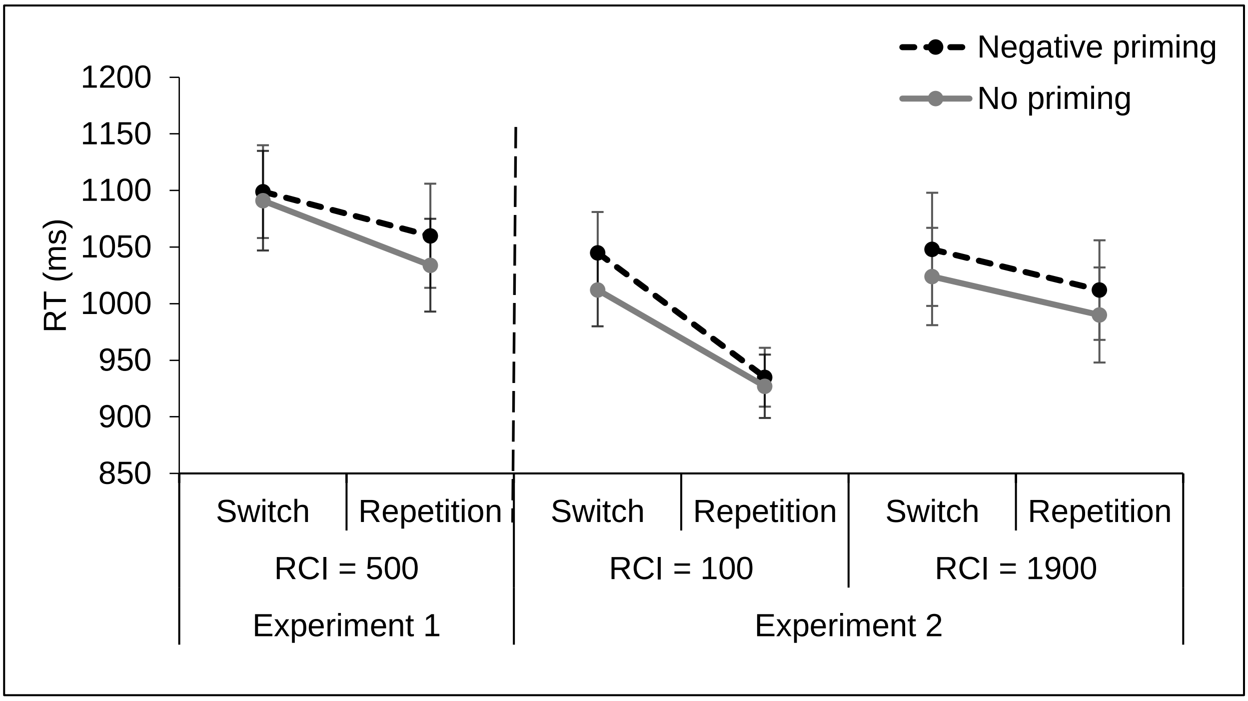

Figure 1. RT (in ms) as a function of attention switch (switch vs. repetition), priming (negative priming vs. no priming) in Experiment 1 and additionally RCI (100 vs. 1900) in Experiment 2. Error bars indicate standard errors.

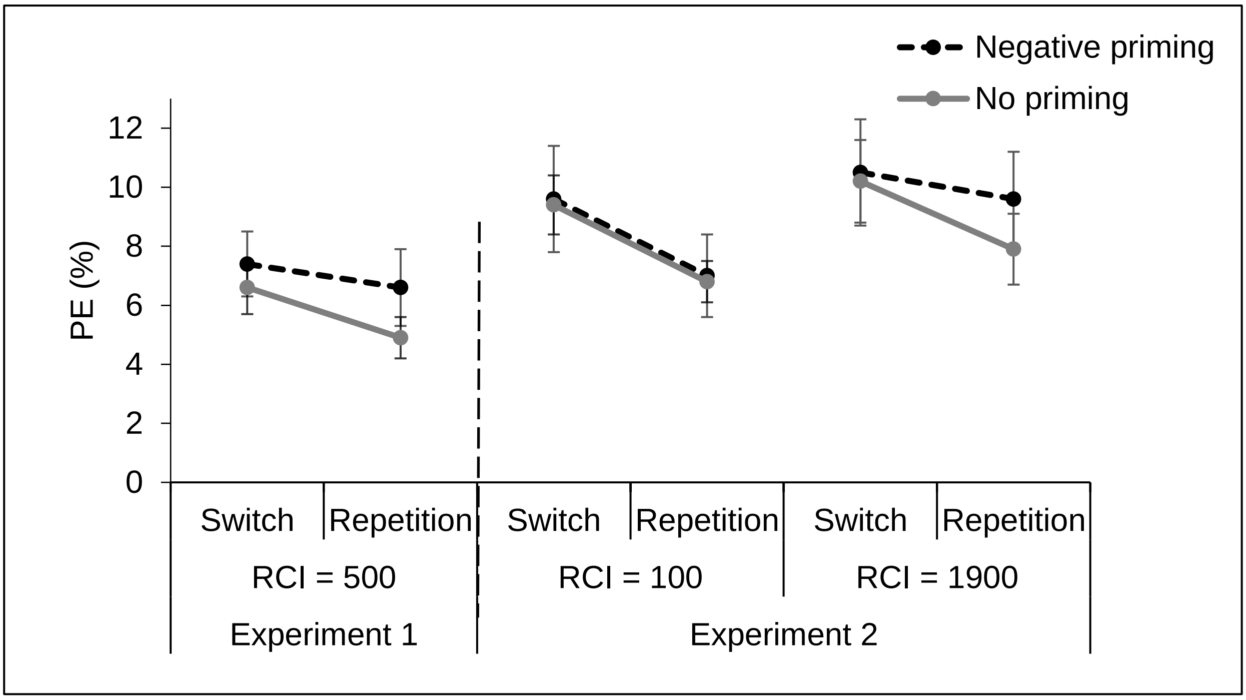

Figure 2. Percentage errors (in %) as a function of attention switch (switch vs. repetition), priming (competitor priming vs. no priming) in Experiment 1 and additionally RCI (100 vs. 1900) in Experiment 2. Error bars indicate standard errors.

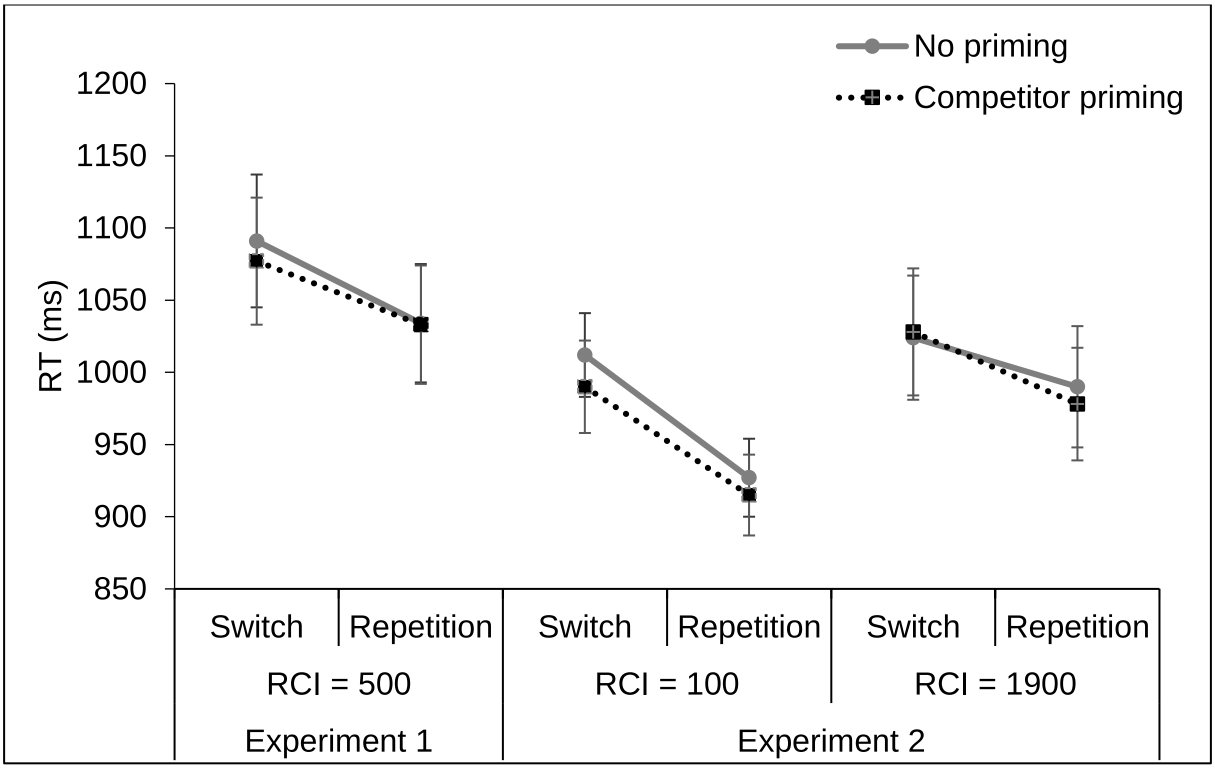

Figure 3. RT (in ms) as a function of attention switch (switch vs. repetition), priming (competitor priming vs. no priming) in Experiment 1 and additionally RCI (100 vs. 1900) in Experiment 2. Error bars indicate standard errors.

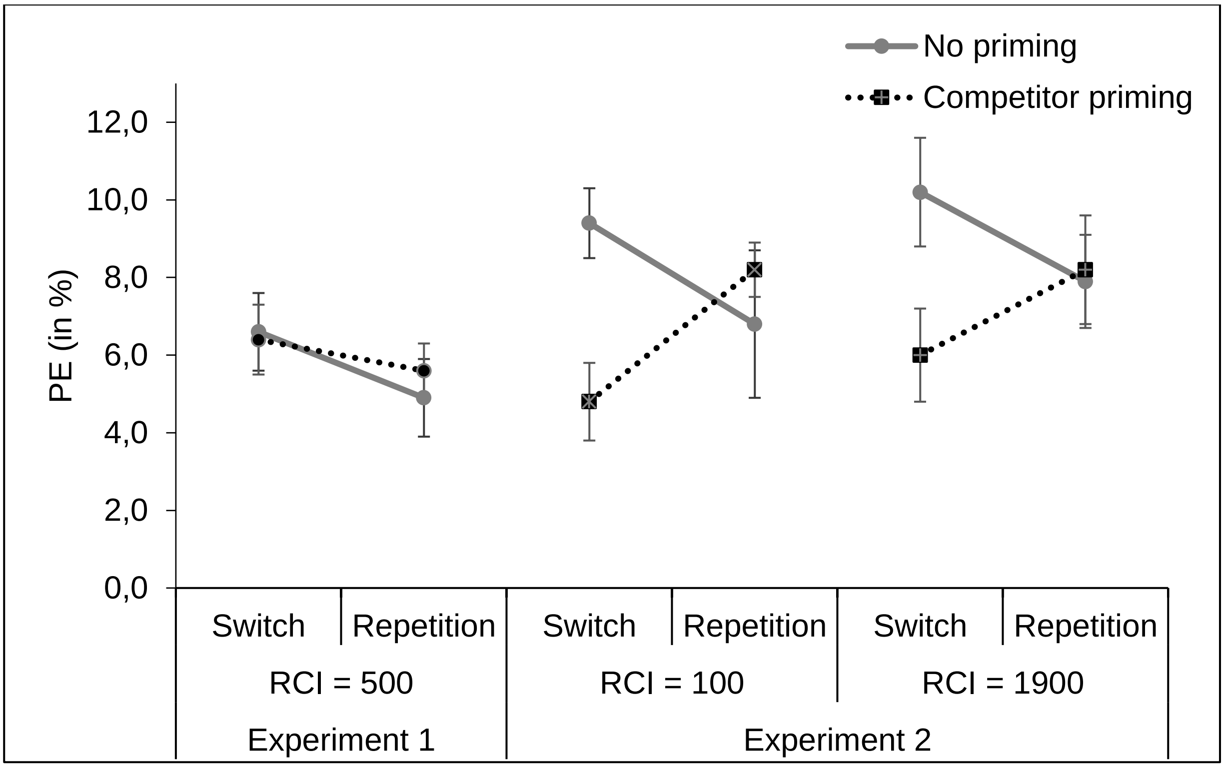

Figure 4. Percentage errors (in %) as a function of attention switch (switch vs. repetition), priming (competitor priming vs. no priming) in Experiment 1 and additionally RCI (100 vs. 1900) in Experiment 2. Error bars indicate standard errors.