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Negative Priming Persists in the Absence of Response-Retrieval

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Abstract. The hypothesis that retrieval of the prime response is responsible for the negative priming (NP) effect has gained popularity in recent studies of visual identity NP. In the current study we report an experiment in which we aimed to remove the response from the prime memory trace by means of spatio-temporal separation. Compared to an identical experiment without this separation (Ihrke et al., 2011), we find that the response-retrieval-specific interaction is absent indicating that the separation was successful in preventing response-retrieval. Still, both negative and positive priming are present as main effects which show that processes other than response-retrieval can produce NP. In addition, based on recordings of the eye-movements during task processing, we localize the NP effect in a target-selection process while positive priming manifests in facilitated response-selection. Our results are in line with a multiple-route view of NP.

Keywords: negative priming, response retrieval, episodic retrieval, event-files

In contrast to general priming paradigms which are used to evaluate how degrees of “preparedness” for a given stimulus affect the reaction time (RT), the negative priming (NP) paradigm allows to investigate how ignored information is processed. NP is a label for the empirical effect of prolonged RTs when a previously ignored stimulus has to be attended to and was first reported by Dalrymple-Alford and Budayr (1966) in a Stroop-like ink-naming task. This initial finding was followed by a large number of studies and the NP effect has been measured in a variety of paradigms and using quite different stimuli (for reviews, see Fox, 1995; Mayr & Buchner, 2007).

Initially, NP has been explained by persisting inhibition (Houghton & Tipper, 1994; Neill, 1977; Tipper, 1985; Tipper & Cranston, 1985): Because an abstract, semantic representation of the distractor stimulus was inhibited during prime processing in order to facilitate target recognition, its activation in the probe as target would take longer. Inhibition theory is very attractive both because it has the ability to explain many interesting effects that modulate NP such as distractor saliency (Grison & Strayer, 2001; Lavie & Fox, 2000; Tipper, Meegan, & Howard, 2002), depth-of-processing (Yee, Santoro, Grey, & Woog, 2000), or semantic priming effects (Damian, 2000) and because an inhibitory component has been observed in other experimental paradigms, for example, task-switching (Grange, Juvina, & Houghton, 2012) and Stroop-tasks (Juvina & Taatgen 2009).

However, as the wealth of empirical studies increased, results inconsistent with this theory emerged and theories incorporating retrieval from episodic memory as a mechanism underlying NP were derived. In addition, many factors were identified that can modulate, cancel, or even reverse the NP effect. This triggered a lively and controversial debate concerning the mechanisms of NP and resulted in an abundant number of single-mechanism theories of NP (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998; Neill, 1977; Neill, Valdes, Terry, & Gorfein, 1992; Park & Kanwisher, 1994; Rothermund, Wentura, & De Houwer, 2005; Schrobsdorff et al., 2007; Tipper & Cranston, 1985). The complex pattern of results made it very difficult, if not impossible, to account for all of them in the framework of a single theory and multideterminant approaches have been suggested (e.g., May, Kane, & Hasher, 1995; Neill, 2007; Tipper, 2001) that assume a combination of inhibitory and memory mechanisms. These accounts state that which mechanism is dominant will depend on the concrete experimental task, context, and induced behavioral strategies.

In visual identity priming studies, NP seems to be well described by episodic-retrieval-based theories (Neill, 1997; Neill & Valdes, 1992; Neill et al., 1992) that attribute the characteristic delay in RT to a conflict between a retrieved memory trace and the current task requirement. The theory argues that automation and optimization processes during trial-processing will lead the participants toward using

Inhibition theory predicts the NP effects to be localized in the target-identification phase: Activating the semantic representation of a target above threshold (i.e., identification) takes more time when it was inhibited during prime processing. On the other hand, episodic retrieval and more specifically response-retrieval theories would argue for a late effect when the correct response is to be initiated. Thus, the two main theoretical accounts of NP make opposite predictions as to the location of the NP effect in our experiment. Since we aimed at excluding the impact of response-retrieval on the NP effect in our experiment, we expect the NP effect (if present in the full RTs) to occur in the target-selection phase as predicted by inhibition theory.

Method

In order to ensure statistical comparability to our previous study (Ihrke et al., 2011), we used the exact same setup: Two overlapping pictograms of everyday-objects in different colors were presented and the target had to be compared to a reference word, resulting in a semantic comparison task (see Figure 1).

Participants

Sixteen (eight male, eight female) participants took part in the experiment. Their age ranged from 21 years to 35 years ($M = 24.9$ years, $SD = 3.3$ years). Participants were compensated for their efforts either by course credits or were paid ($\text{€}10 \approx 14$ USD). All participants had normal or corrected-to-normal vision and were right-handed. All participants were naive to the purpose of the experiment and had not taken part in a previous study employing similar stimulus material.

Stimuli and Apparatus

We used a stimulus set and experimental setup identical to the one from Ihrke et al. (2011), consisting of six characteristic line-drawings of everyday-objects. These drawings represented the objects “bus,” “ball,” “tree,” “book,” “bed,” and “bench.” The area covered by the objects was approximately equal and the drawings were prepared in a way to approximate constant visual complexity. The words corresponding to the used pictograms appear frequently in everyday-language. In the experiment, the target and the distractor object appeared superimposed such that large portions of the drawings overlapped but both objects were clearly discernible. The distractor appeared in red ($\text{RGB} = \{255, 0, 0\}$), the target in green ($\text{RGB} = \{0, 255, 0\}$), and both objects appeared in the uppermost part of the display. A reference word corresponding to one of the six objects (either the target or one of the objects not shown) was presented at the lowermost part of the display.

Stimuli were presented on a standard 19 inch SVGA monitor and participants were seated at a distance of 1 m from the monitor. The target-distractor compound subtended

a horizontal angle of 5.0 visual degree and a vertical angle of 3.15 visual degree. The distance between target/distractor stimuli and reference word was 10.1 visual degree and it was not possible to see or identify the reference word while fixating the target and distractor stimuli. This spatial separation of target/distractor and reference was the only difference to Ihrke et al.'s (2011) study where target, distractor, and reference could be processed together (distance between target/distractor and reference was 0.5 visual degree). Participants were required by instruction to first identify target and distractor, then to look at the reference word and, finally, to compare target and word. Responses were given by two dedicated buttons at the left and right hand. The yes-no mapping to left or right hand was balanced across subjects. Presentation of stimuli and acquisition of the subject's response were controlled by a program implemented using Presentation software (Version 9.20, <http://www.neurobs.com>).

Design

The experiment realized a 2×5 design with response-repetition (repetition vs. switch) and stimulus-repetition (priming) as within-subject factors. Five different priming conditions were realized: control, target repetition (TT), negative priming (DT), distractor-repetition (DD), and a target-to-distractor condition (TD). Response- and stimulus-repetition were varied independently of each other and trials were presented in a pseudorandomized fashion following a trial sequence that was generated using a software specifically designed for avoiding sequence structure (Ihrke & Behrendt, 2011). Each of the pictograms appeared an equal number of times (both as target and distractor) and the number of trials was counterbalanced across the priming conditions (including control) and response-repetition. The resulting overrepresentation of trials with repeated objects was chosen (1) to promote retrieval-based processing which is triggered when many object-repetitions are presented (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997) and (2) to ensure comparability to our previous study (Ihrke et al., 2011). Each object appeared an equal number of times as reference word.

In addition to RTs and error rates, we considered partial RTs as dependent variables: The experimental protocol enforced a strictly serial processing of target- and response-selection and both processes were separated by a prominent, vertical eye-movement. We therefore analyzed both, the target-selection RT (R_{ts} ; duration from stimulus-onset to eye-movement) and the response-selection RT (R_{rs} ; time from eye-movement to response).

Procedure

Participants were tested individually in sessions that lasted no longer than 60 min. Before the experiment proper, participants were introduced to the stimuli and their associated labels. Instructions were to compare the green target object to the reference word as quickly and correctly as possible

while ignoring the red distractor object. In addition, participants were instructed to perform only a single eye-movement in the direction from target/distractor to the reference word. After a practicing phase of 30 trials, the experiment started, consisting of 840 trials. The trials were divided into 10 blocks of 84 trials each. The participants took short breaks between blocks.

Each trial consisted of: (a) a fixation cross for 500 ms at the location of the distractor/target stimuli (i.e., at the top of the screen); (b) a display containing two superimposed objects and a word (until the subject responded, but no longer than 2 s); (c) a blank screen providing a randomized response-to-stimulus interval between 500 and 1,500 ms (blank screen + fixation cross).

Outlier Correction

Trials with erroneous responses in the prime (2.45%¹) or in the probe (2.45%) were not considered in the analyses. Furthermore, RTs below 250 ms or above 3,000 ms were excluded from the analyses, as well as those with a difference to the mean in the same experimental condition exceeding two times the standard deviation (3.57%). In addition, trials in which more than one eye-movement was detected or where the results of the detection in both vEOG electrodes was inconsistent were removed from the dataset (1.14%). Overall, not more than 10% of the trials for each participant were excluded from the analysis.

Extraction of Partial Reaction Times

Electroocular data are often used to record eye-movements (Joyce, Gorodnitsky, King, & Kutas, 2002) by measuring the electric potential fluctuations due to the movement of the eye: The angle of the eye-movement is approximately proportional to the resulting change in the recorded potential. In the setting described here, it was sufficient to obtain a valid measure of the onset of the first major saccade downwards during each experimental trial (see Appendix). Four EOG electrodes (left and right hEOG and vEOG, respectively) were attached 1 cm below the left and right eye, and at a distance of 1 cm from the outer left and right canthi, respectively. The sintered ring electrodes were made of highly conductive material (Ag/AgCl).

Results

Analyses of the error rates did not provide any significant results and are therefore not considered further. For a descriptive summary of the RTs and error rates, see Tables 1 and 3.

¹ Numbers are median rates between-subjects.

Comparison With Ihrke et al. (2011)

The current study was, apart from the spatio-temporal separation of the stimuli, an exact replication of a previous study Ihrke et al. (2011) and we conducted a mixed 2 (study) × 5 (priming: control, DT, TT, TD, DD) × 2 (response-repetition) ANOVA with study as a between-subjects factor and priming and response-repetition as repeated-measures factors. The analysis revealed a main effect of study, $F(1, 30) = 6.95, p < .05$, as well as for priming, $F(4, 120) = 5.46, p < .001$, and response-repetition, $F(1, 30) = 9.58, p < .01$. There was a significant interaction of study and priming, $F(4, 120) = 3.86, p < .001$, and also the three-way interaction Study × Priming × Response-Repetition reached significance, $F(4, 120) = 6.39, p < .001$. The pattern of results concerning the Stimulus × Response-Repetition effects was thus different in the two studies and fine-grained analyses were carried out to find whether the Stimulus × Response-Repetition interaction vanished as expected.

Priming and Response-Repetition Effects

We conducted a global 5 (priming) × 2 (response-repetition) ANOVA treating the factors as repeated measures. We found a main effect of priming, $F(4, 60) = 7.93, p < .001$, a main effect of response-repetition, $F(1, 15) = 9.50, p < .01$, and an interaction of the two, $F(4, 60) = 5.58, p < .001$. We conducted separate 2 (priming: CO vs. priming) × 2 (response-repetition) ANOVAs per priming condition using Holm's (1979) method for adjusting the p values to account for the familywise error rate. Priming was significant as a main effect in the TT, $F(1, 15) = 8.06, p < .05$, and the DT conditions, $F(1, 15) = 5.46, p < .05$, but not in the TD, $F(1, 15) = 1.16, ns$ and DD, $F(1, 15) = 1.03, ns$ conditions. One-sided, paired t -tests showed an advantage of 19 ms for the TT condition, $t(31) = 3.14, p < .01$, and a delay of -17 ms for the DT condition, $t(31) = 2.58, p < .01$. There was a significant main effect of response-repetition in the TT, $F(1, 15) = 17.30, p < .01$, the DT, $F(1, 15) = 4.94, p < .05$, and the TD condition, $F(1, 15) = 25.51, p < .001$, but not in the DD condition, $F(1, 15) = 1.70$. The most relevant Priming × Response-Repetition interaction reached significance only in the DD condition, $F(1, 15) = 7.69, p < .05$.

Strategy-Switching

Given that the interaction of priming and response-repetition reached significance in the global analysis (due to the significant interaction in the DD condition), participants seemed to have been able to make use of retrieved response-information from the prime in some cases. This is in contrast to our objective to remove this possibility by means of spatio-temporal separation. We hypothesize that participants,

Table 1. Summary of mean reaction times (RTs) by stimulus- and response-repetition condition. In addition to the data from the current study (column “separation”), the corresponding results from Ihrke et al.’s (2011) study are presented (column “no separation”). Note the disappearance of the Priming \times Response-Repetition interaction in the case of a spatio-temporal separation

	Mean RT ^a			
	Same response		Different response	
	Separation ^b	No separation ^c	Separation	No separation
Control	941.1 (129.3)	838.4 (154.4)	920.10 (140.2)	821.2 (139.7)
DT (NP)	950.9 (143.4)	829.5 (139.9)	943.41 (140.3)	842.0 (156.3)
TT (PP)	930.9 (130.7)	816.7 (120.5)	892.64 (124.6)	835.8 (136.8)
TD	947.9 (144.2)	840.7 (144.4)	923.42 (136.0)	814.9 (149.4)
DD	934.1 (148.7)	824.4 (158.0)	938.16 (139.7)	817.6 (146.8)
	Priming effects ^d			
DT (NP)	-9.8	8.9	-23.31	-20.8
TT (PP)	10.1	21.7	27.46	-14.5
TD	-6.8	-2.3	-3.32	6.3
DD	7.0	14.0	-18.05	3.6

Notes. Target repetition (TT), negative priming (DT), distractor-repetition (DD), and target-to-distractor condition (TD).

^aStandard-deviation in parentheses.

^bThese are data from the experiment with spatio-temporal separation of target and reference reported here.

^cThese data are taken from Ihrke et al. (2011) which implemented the same paradigm without spatio-temporal separation.

^dDifference of control and priming condition.

during the course of the experiment, developed behavioral strategies to optimize responding: Training in a cognitive task can lead to the usage of increasingly efficient cognitive strategies (Jansen & van der Maas, 2002). In our experiment, for example, subjects could have relied on an afterimage strategy: Fixating the target and distractor objects only very briefly and processing the afterimage during and after the saccade could have resulted in a binding between the response and the stimuli. This binding could, in turn, have been retrieved during probe processing, thereby causing the observed interaction. The fact that the red (and therefore most salient) distractor caused response-retrieval in the case of a direct repetition (DD) is congruent with this idea. Such a shift of strategy – from sequential processing to an afterimage-based approach – would manifest in the statistics of the data.

Table 2. Model-selection table for HMMs with 1–3 states, a linear regression model and a two-state model with constraints (see text for details). Note that the BIC has a local minimum at $m = 2$ and that the constraint further improves the model

Model	BIC	log L	n_{free}
$m = 1$	10,298	-5,142	2
$m = 2$	10,089	-5,021	7
$m = 3$	10,094	-5,000	14
linear	10,105	-5,042	3
$m = 2$, constr	10,078	-5,022	5

² We used the trialwise mean over subjects since all subjects were presented with the same pseudo-randomized trial-sequence. Taking the mean over subjects therefore results in an estimate for the expected value for the RT for each trial.

We employed a generalized fluctuation test (Kuan & Hornik, 1995) using a recursive CUSUM test as implemented in (Zeileis, Kleiber, Krämer, & Hornik, 2003; Zeileis, Leisch, Hornik, & Kleiber, 2002) to test for structural breaks in our time-series.² This approach tests the null-hypothesis that the mean μ_0 of a time-series is constant $H_0: \mu_0 = c$ against the alternative that it changes over time. This test yielded significant results, $S = 3.858$, $p < .001$, indicating that there was a structural break in the time-series. In order to test the hypothesis that this corresponds to a shift in behavioral strategies, we analyzed the data in different parts of the experiment. In case that a strategy-shift was present, we would expect to find the Priming \times Response-retrieval interaction only in later parts of the experiments.

We split the data in half and analyzed separately the first and last 420 trials. As argued above, participants were expected to show the interaction in the second but not in the first part of the data. The 2 (part: first vs. second) \times 5 (priming) \times 2 (response-repetition) repeated-measures ANOVA produced Significant part \times Priming, $F(4, 60) = 3.51$, $p < .05$, and Part \times Response-Repetition interactions, $F(1, 15) = 5.88$, $p < .05$. Also, the three-way Part \times Priming \times Response-Repetition interaction reached significance, $F(4, 60) = 3.03$, $p < .05$. Separate ANOVAs for the two parts revealed a significant Priming \times Response-Repetition interaction in the second half of the experiment, $F(4, 60) = 4.09$, $p < .01$, but not in the first part, $F(4, 60) = 1.97$, *ns*. There was a main effect of priming in both halves (first: $F(4, 60) = 7.61$, $p < .001$; second: $F(4, 60) = 3.91$, $p < .01$) as well as a main effect of

Table 3. Summary of partial reaction times R_{ts} and R_{rs} , full reaction times and error rates. Standard deviations are given in parentheses

	Mean RT			Error rates
	R_{ts}	R_{rs}	full ($R_{ts} + R_{rs}$)	
Control	414.4 (101.8)	516.2 (62.5)	930.6 (133.1)	3.8 (3.6)
DT (NP)	425.3 (104.5)	521.9 (72.2)	947.1 (139.6)	3.4 (3.2)
TT (PP)	409.4 (94.5)	502.4 (58.6)	911.8 (127.1)	2.7 (2.7)
TD	422.0 (110.8)	513.7 (68.1)	935.7 (138.4)	3.7 (3.8)
DD	413.9 (103.6)	522.3 (70.1)	936.1 (142.0)	3.8 (3.3)
Priming effects				
DT (NP)	-10.9	-5.7	-16.6	0.4
TT (PP)	5.0	13.8	18.8	1.1
TD	-7.6	2.5	-5.1	0.1
DD	0.5	-6.1	-5.5	0.0

Notes. Target repetition (TT), negative priming (DT), distractor-repetition (DD), and target-to-distractor condition (TD).

response-repetition (first: $F(1, 15) = 15.78, p < .01$; second: $F(1, 15) = 4.24, p < .05$). Most notably, the Stimulus \times Response-Repetition interaction for the DD condition was significant only in the second part of the experiment (first: $F(1, 15) = 0.03, ns$; second: $F(1, 15) = 6.40, p < .05$).

Seeing that priming and response-repetition effects differed between the first and the second part of the experiment, we wished to confirm the strategy-switching hypothesis by complementary analyses allowing to estimate the precise nature of the structural breaks in our data. A convenient class of models to address this question are Hidden Markov Models (HMM; Zucchini & MacDonald, 2009). Similar to independent-mixture models, HMMs assume that there are discrete states each of which produces a response according to a dedicated probability distribution (emission probabilities). The distinguishing feature is that the switching between the states does not occur independently, but that it is assumed to be a Markov-process (i.e., the probability of each state in trial i depends only on the $i - 1$ 'th state) which is the reason that they are also referred to as dependent-mixture models (Visser & Speekenbrink, 2010). A complete coverage of HMMs is out of the scope of this article and we refer the interested reader to the excellent book by Zucchini and MacDonald (2009) and to Visser, Raijmakers, and Molenaar (2002) and Visser, Raijmakers, and Maas (2009) for their application in a psychological context.

We used the depmixS4 software (Visser & Speekenbrink, 2010) for the subsequent analyses: HMMs were fitted to the time-series of mean RTs as a function of trial number resulting from averaging the RTs from all subjects for any one trial. To fit a HMM to data, the number of states m must be specified. The problem of selecting this parameter is known as "model selection." It can be resolved by using the minimum of the Bayesian information criterion (BIC) which implements a trade-off between log-likelihood of the model and the number of free parameters n_{free} . We fitted three HMMs with increasing number of states to our data and calculated this criterion for each of them (see Table 1). The BIC has a minimum at $m = 2$ and we therefore chose the two-state model. To show that there was indeed a switch

of strategy rather than an overall training effect, we fitted a linear regression model to the same data. The linear model performs worse than the two-state HMM in terms of the BIC (see Table 2), indicating that the data are better explained by strategy-shifting than by continuous training.

To improve the fit of the model, it is possible to introduce constraints on the parameter space of the HMM. Associating the states with different behavioral strategies, it is reasonable to assume that the subjects started with a naïve strategy and switched to a more refined one. We therefore fixed the initial distribution over the states to $P(S_0 = 1) = 1$ and $P(S_0 = 2) = 0$ where S_0 is the initial state. In addition, we constrained the transition matrix such that there was no going back to the old strategy once the switch had been made $P(S_t = 1 | S_{t-1} = 2) = 0$ and $P(S_t = 2 | S_{t-1} = 2) = 1$. This constraint is justified by the assumption that a superior strategy will not be dropped once it has been successfully adopted (Schmittmann, Visser, & Raijmakers, 2006). The two constraints resulted in a further improvement of the model as reflected in a decrease of the BIC. This model resulted in a slower state with mean $\mu_1 = 1035.97$ and standard deviation $\sigma_1 = 107.40$ and a faster state with mean $\mu_2 = 928.34$ and standard deviation $\sigma_2 = 85.41$. The state-transition took place at trial 394 (see Figure 2).

Partial Reaction Times

The one-factorial ANOVA with priming (CO, DT, TD, TT, DD) as a repeated-measures factor on the partial RTs produced a significant effect of priming for both RTs (target-selection R_{ts} : $F(4, 60) = 4.79, p < .01$; response-selection R_{rs} : $F(4, 60) = 5.63, p < .01$). In the target-selection RT, two-tailed t -tests testing control versus the priming conditions revealed that the main effect of priming was caused by significantly delaying DT, $t(15) = 2.37, p < .05$ (-10.9 ms) and TD effects, $t(15) = 2.77, p < .05$ (-7.6 ms). In contrast, the same analysis using the second part of the RT found only a significant facilitative effect for TT, $t(15) = 2.75, p < .01$ (13.8 ms). The p values were

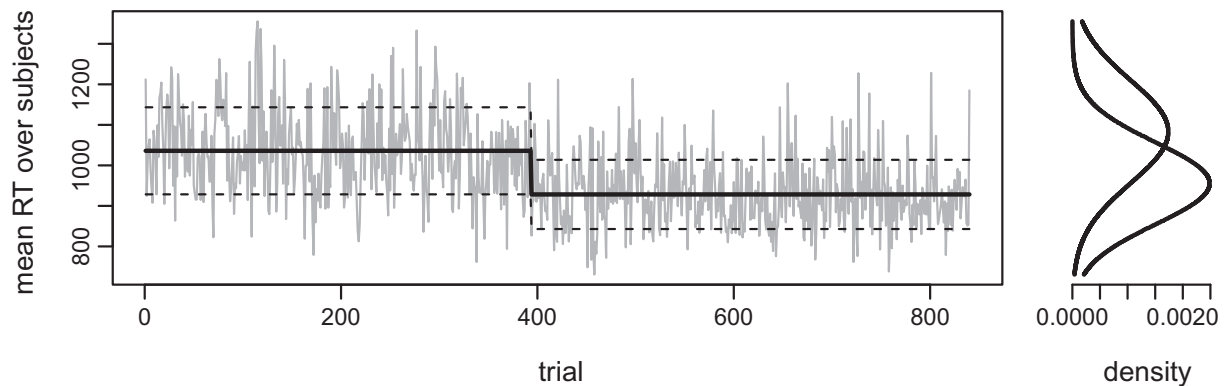


Figure 2. Time-series and the constrained two-state HMM. The mean (solid black) and standard deviation (dashed black) of each active state are plotted along with the data (gray). The right plot shows the density of the state distributions. The state-transition occurred at trial 394.

adjusted according to Holm 1979's method. To exclude the possibility that the facilitative effect on response-selection in the TT condition was caused by priming between prime and probe reference,³ we compared the means of the response-selection RTs in TT-switch (17.5 ms) and TT-repetition (10.2 ms) trials. The effect is in the opposite direction and not significant, $t(15) = 0.94$, $p = .36$. We conclude that no reference-priming is observable.

Discussion

The main result of the experiment confirmed our hypothesis: Introducing a spatial and temporal separation of target/distractor compound and reference word changed the pattern of stimulus- and response-repetition effects. The response-retrieval-specific Priming \times Response-Repetition interaction for TT and DT disappeared. Instead, a main effect of priming was observable in our data. We argue that this result is in support of dual-mechanism accounts of NP (e.g., Tipper, 2001). NP persists even if response-retrieval can be excluded as an explanation and thus, a second mechanism must be responsible for the effect.

In a previous study it has been shown that priming effects depend on response-repetitions in precisely the same experimental setup lacking the spatio-temporal separation introduced here (Ihrke et al., 2011). Our hypothesis was restricted to DT and TT trials, because response-retrieval is dependent on the role of the repeated stimulus during probe processing: Only conditions in which the probe target had previously been seen evoked retrieval of the prime response (Ihrke et al., 2011). The complementary priming conditions, DD and TD, were included to ensure comparability to Ihrke et al. (2011). This was necessary, because it is known that NP depends on the mix of experimental conditions in the experiment (e.g., Frings & Wentura, 2008).

However, priming effects in the DD and TD conditions were not significant.

We argued that the separation of target/distractor and reference word prevented the response to be encoded in the same event-file as the stimuli (Hommel, 2005). There is an alternative explanation for our results that is based on the assumption that participants named the target-stimulus internally: Such a concealed vocalization could be regarded as "response" and our paradigm would consequently be equivalent to a target-naming paradigm. As Rothermund et al. (2005) pointed out these experiments confound priming condition and response-repetition: DT is always associated with a response-switch while TT always repeats the target-identity and therefore the response. Interpreting our setup as consisting of a selective-attention task (name the green object, ignore the red one) and a comparison task (compare a written word to the memorized target-label), one could argue that the subsequent presentation of a new target/distractor would retrieve the memory trace including the subverbal "response" (the label) of the previous target. Similar to classical naming paradigms, this would then be expected to lead to the observed main effects because the retrieved response is congruent in the TT condition but incongruent in the DT case. However, evidence against this notion comes from the analysis of the partial RTs. If the above argument was correct, a facilitative effect for TT and a NP effect for DT should have been observed in the target-selection (and -naming) RT, R_{ts} . This was not the case: The usually more prominent positive priming effect was only observable in the second time-window in which the response had to be selected by comparing target to reference word. We therefore interpret the absence of the Response-Repetition \times Priming interaction as evidence for a process in addition to response-retrieval responsible for NP.

In potential conflict to our hypothesis, we observed a significant Response-Repetition \times Priming interaction in the distractor-repetition (DD) condition. If the binding between

³ Note that the TT condition with response-repetition is the only condition in which the reference word is consistently repeated between prime and probe.

stimuli and response would have been prevented by our manipulation, this interaction should not have been observed. We hypothesized that participants, over the course of the experiment, optimized their behavior strategically in a way that allowed them to successfully use retrieval-based strategies. A structural change in our data, as indicated by the CUSUM test, supports this interpretation. One possibility for such a strategy enabling the use of response-retrieval is based on the usage of an afterimage instead of semantic stimulus-representations. It is unlikely, however, that participants made use of such sophisticated strategies from the beginning of the experiment. We therefore separately analyzed the two sets of trials obtained by splitting the experiment in half. From this analysis, we conclude that participants did indeed change their strategies in the course of the experiment: The response-retrieval-specific interaction was present in the second but not in the first part of the experiment. Additional analyses using Hidden Markov models supported this idea: A constrained two-state model with a single state-transition accounted best for our data indicating that participants switched strategies during trial-processing.

The main effect of priming in the DT and TT conditions was not caused by response-retrieval as argued above. Following the argument of dual-mechanism theories (May et al., 1995; Neill, 2007; Tipper, 2001), we assume that an inhibitory mechanism was responsible for the observed effects. The results of our analyses of the partial RTs are in line with this interpretation: Our experimental setup allowed to measure separate RTs for the target-selection process (during which the target was separated from the distractor) and a response-selection (comparison) process. We found that the NP effect was exclusively due to delays in the target-selection RT – a finding well explained by inhibition theory postulating a delay in the activation of the previously inhibited representation of the target object.

The finding that the positive priming effect in the target-repetition condition manifested in the response-selection RT while target-selection was not speeded up significantly is rather surprising. Typically, positive priming is thought to be a perceptual effect (Behrendt et al., 2010) and the TT-effect was thus expected in an early time-window. However, when analyzing our experimental setup in detail, it is apparent that a perceptual facilitation is unlikely to occur. The prime and probe target/distractor stimuli do not follow one another immediately; Rather, there is an intervening reference word which could have effectively masked any perceptual repetition effects. Target-repetition is the only priming condition in which the repeated object has been compared to the reference word in the prime and has therefore received strong semantic activation in the prime. Hence, the facilitative effect in the late RT can be thought of as operating on a semantic level. This supports the hypothesis that repetition priming operates on more than one level of processing: When no “masking” of the prime stimuli is used, PP effects are usually much stronger (≈ 130 ms) using similar stimuli (Behrendt et al., 2010). Arguably, this is due to the fact that priming processes on both a perceptual and a semantic level operate in this setting while in our paradigm only the semantic level was available.

In summary, we were able to show that negative and positive priming emerge independently of response-repetitions when there is no response-retrieval. In addition, a separation of target- and response-selection processes revealed a distinction of the origin of negative and positive priming effects: While NP was caused in the initial target-selection phase, positive priming manifested in the later response-selection process. We interpreted our results in terms of a dual-mechanism theory which postulates an interaction of inhibition and retrieval-mechanisms to be responsible for the priming effects.

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Appendix

Extraction of the Partial Reaction Times

Extracting the latency of the first downward saccade was done using the following procedure. In a first step, the data from the EOG channels were low-pass filtered at 20 Hz and segmented based on stimulus-onset. Let $s_j^c(t) \ t \in \{1, \dots, n\}, j \in \{1, \dots, N\}, c \in \{\text{rvEOG}, \text{lvEOG}\}$ be the N segments of length n sampling points obtained from the two vEOG channels. A function W depending on a window size w given in sampling points can be constructed that relates the sampling points to the largest difference between two data points in the time window w by

$$W_{j,w}(t) = \text{sgn}(\tau_{\max} - \tau_{\min}) |s_j^c(\tau_{\max}) - s_j^c(\tau_{\min})|,$$

where

$$\tau_{\max} = \arg \max_t S_{t,w} \quad \text{and} \quad \tau_{\min} = \arg \min_t S_{t,w},$$

and

$$S_{t,w} := \left\{ s_j^c(i) \mid i \in \{t, \dots, t+w\} \right\}.$$

Finding the latency R_j^c of the largest vertical eye-movement detected in electrode c is equivalent to solving

$$R_j^c = \arg \max_t (W_{j,w}(t)),$$

which gives the desired latency in sampling point units. In order to increase the validity of this measure, the procedure was carried out for the two vEOG electrodes separately and then averaged

$$R_j = \frac{R_j^{\text{lvEOG}} + R_j^{\text{rvEOG}}}{2}.$$

In the case that the two estimates of the eye-movement differed significantly (more than a fixed criterion C)

$$|R_j^{\text{lvEOG}} - R_j^{\text{rvEOG}}| > C,$$

the trial was marked as *invalid* and excluded from the analysis. In the analysis described here, a sampling rate of 100 Hz was chosen, resulting in $n = 200$ sampling points in the 2 s post-stimulus. The time-window was chosen as $w = 20 \text{ ms} \equiv 2$ sampling points and the criterion for invalid trials was fixed as $C = 100 \text{ ms} \equiv 10$ sampling points.