

Semantic Inhibition due to Short-Term Retention of Prime Words: The Prime-Retention Effect and a Controlled Center-Surround Hypothesis

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Abstract

The semantic priming effect is shown to be modulated by the instruction to maintain the prime word while conducting a lexical decision to the target. Specifically, the priming effect is absent in situations of prime-retention. An extended version of Dagenbach and Carr's (1994) Center-Surround hypothesis is proposed, in which the prime-retention effect, the absence of priming under prime-retention, can be accommodated. This extended hypothesis suggests that under prime-retention, activation remains centered on the prime, preventing unwanted spread of activation. This impact of the on-center-off-surround mechanism increases over time, making it sensitive to manipulations of stimulus duration.

Introduction

In the field of memory, semantic priming is a basic paradigm used to investigate the processes that inter-relate conceptual representations in long-term memory. The basic result is reduced lexical decision times or naming latencies and improved accuracy to words (i.e., targets), when they are preceded by a related word (i.e., the prime) relative to control. The semantic priming effect is such a robust phenomenon that even the absence of priming is theoretically relevant, as can be seen by the large literature on the prime-task effect (the absence of priming when attention is allocated away from the semantic level, but is still within the verbal domain) (see for a review, Maxfield, 1997). The implied assumption in the priming literature seems to be that the more attention the prime word receives, the more priming is expected. This paper focuses on the counterintuitive observation that the semantic priming effect is absent when in a standard priming paradigm the prime has to be reported *after* making a lexical decision to a target. This observation will be referred to as the *prime-retention effect*, as it is the active retention of the prime in short-term memory that modulates the priming effect.

Controlled Center-Surround Hypothesis

There are a number of theories and models of priming, but for the present purposes the spreading-activation view of semantic priming will be addressed to highlight the need for auxiliary mechanisms to accommodate the to-be-presented data. In the standard spreading-activation theory, concepts in semantic memory are linked together to form a semantic network, with the strength of the connection between two concepts representing the strength of association. Extensive investigations into the nature of the semantic priming effect

has led to the view that the semantic priming effect is due to a fast-acting automatic process and a slow-acting controlled process (Neely, 1976, 1977, 1991). By varying the stimulus-onset-asynchrony (SOA) between the prime and the target, the relative contributions of these processes can be modulated. It is therefore assumed that with short SOAs the priming effect is predominantly due to automatic processes. However, this assumption has been challenged by behavioural and neuroimaging studies that show context effects at short SOAs (e.g., Mummery, Shallice & Price, 1999; Smith, Besner & Miyoshi, 1994).

One theory that specifically addresses the possibility of controlling the spread of activation is the Center-Surround hypothesis by Dagenbach and Carr (1994). In a nutshell, the hypothesis states that there exists a mechanism that facilitates “the semantic code on which it is focused or *centered* while inhibiting *surrounding* codes, codes that are similar to but different from the desired code and are competing with it for retrieval” (p.328, italicised words were between quotes in original). Dagenbach and Carr's work was mainly focused on priming effects found at the threshold of subjective and objective awareness and was applied quite successfully in a model of negative priming (Houghton & Tipper, 1994). However, in the standard supra-threshold priming paradigm, the data does not seem to demand such on-center-off-surround mechanism. This may be because the prime word does not have to be actively maintained. An on-center-off-surround mechanism would be necessary under conditions of prime-retention. For example, when a task requires focusing on a particular word, the increased activation to that word would lead to more spread of activation, which would in turn compromise the attentional focus on the word, due to the now-activated distractors. Intuitively, we are able to focus on the word ‘doctor’ for several seconds without strongly activating related concepts like ‘nurse’, ‘patient’, ‘hospital’, ‘medicine’ and so on. Besides preventing a situation where the whole lexicon becomes activated, inhibitory mechanisms seem particularly relevant in situations of short-term retention where a robust focus is necessary (e.g., Grossberg, 1978).

The view that will be pursued here is that there exists a trade-off between prime-activation and activation-spread, of which the balance depends on the task requirements. This hypothesis will be referred to as the Controlled Center-Surround hypothesis, implying that a controlled effort (i.e., deliberate active maintenance) needs to be made in order to observe the on-center-off-surround mechanism at supra-

threshold SOAs. In the prime-retention paradigm used here, the participant is presented with the prime and has to maintain it while making a lexical decision to a target. The Controlled Center-Surround hypothesis would predict that normal priming effects are found when the prime need not be retained (as the on-center-off-surround mechanism is not fully operational), while in the retention condition the off-surround component nullifies (or even reverses) the priming effect.

Before presenting the experiments that were designed to address the Controlled Center-Surround hypothesis, the next section will highlight two earlier reports that presented hints of a *prime-retention effect*.

Earlier reports

A *prime-retention effect*, the absence of a priming effect when the prime is actively maintained during lexical decision, can be observed in reports from at least two research groups (Fischler & Goodman, 1978; Henik, Friedrich, Tzelgov & Tramer, 1994). In a study by Fischler and Goodman (1978), participants were tested on a masked priming paradigm in which the prime was presented very briefly (50 ms) with a visual mask preceding and succeeding it. They asked participants to report the prime word after making a lexical decision to the target string. Participants were able to report the prime in about 50 % of the trials. Semantic priming was only found when the prime could *not* be reported; the priming effect was absent when participants could correctly report the prime word. A second example of the *prime-retention effect* can be found in one of the conditions in a study by Henik, Friedrich, Tzelgov and Tramer (1994). These authors were interested in the time-course of the prime-task effect (the finding that the priming effect is eliminated when the prime word is processed on a non-semantic level). Participants had to read the prime out loud and make a lexical decision to a target word. In one particular condition (in their experiment 3), the SOA was relatively short (240 ms) and therefore participants had to report the prime word *after* the lexical decision was made, thus actively maintaining it during the lexical decision. No priming effect was found in this condition. Henik et. al. (1994) explained the lack of priming in terms of the prime being processed at a shallow (e.g., phonological) level and thereby preventing resources to be allocated to the semantic level. However, this idea was not elaborated further.

The results by Fischler and Goodman (1978) and Henik, et. al. (1994) suggest at the very least that maintaining the prime modulates the priming effect and that the underlying mechanism may be inhibitory in nature. However, the results indicating this were tangential to the main focus of their investigations and did not receive enough attention. Therefore it is possible that their results, indicating a *prime-retention effect*, may have been a chance-finding. For example, in Fischler and Goodman's (1978) study, the results strongly depended on the erroneous recall performance of the participants (50 % error rate), making the data sensitive to participants' idiosyncratic biases (see

for discussion, Holender, 1986). In addition, the results obtained by Henik, et. al. (1994) were not replicated without participants completing several other experimental conditions, which could have led to carry-over effects.

Experiments

Here, three experiments are reported that were specifically designed to address the *prime-retention effect*. The experiments involved two blocks of prime-target pairs in a standard lexical decision paradigm. The first block was always the control condition, in which participants did not need to maintain the prime word. In the second block, participants were required to maintain the prime and give a verbal report (in Experiment 1) or recognise it from four alternatives (in Experiment 2 and 3) after the lexical decision. In order to assess whether the prime has been processed on the semantic level, the association strength between prime and target was taken into account in the analyses. Any modulation with associative strength would counter an explanation based purely on shallow non-semantic processing.

According to the Controlled Center-Surround hypothesis, in the control condition, normal priming effects are expected for strongly and weakly related targets at both short and long SOAs, as the activation of the prime is allowed to decay after presentation. However, in the retention condition, it is expected that only strongly related targets show priming effects at both SOAs (controlled on-center), but that weakly related targets show less or even no priming effect (controlled off-surround).

Experiment 1

Participants. Twenty volunteers from the University of London participated in the experiment in exchange for £5. All participants had English as their first language, were right-handed and had normal or corrected-to-normal vision.

Design. The experiment conformed to a 3 x 2 within-subject design, with Relatedness (unrelated, low-related, high-related) and Retention as independent variables. Lexical decision times and accuracy were measured.

Materials. Eighty-four word pairs were selected from the MRC Psycholinguistic Database (Coltheart, 1981). The word pairs had a word frequency ranging from 10 to 660 per million (Kucera & Francis, 1967). The association strengths between the prime and target word ranged from 12.5 to 73.8 (M=34.5; Moss & Older, 1996). A median split divided the targets in the high and low association trials. All words and pseudohomophones were one syllable long. Unrelated trials were formed by rearranging the related pairs. Each participant saw each word only once, but target words rotated across participants in all conditions.

Apparatus. The experiment was run on an IBM-compatible PC using Micro Experimental Laboratory (MEL) Professional software (Schneider, 1995). Letter size was approximately 0.5 cm and average viewing distance was about 50 cm.

Procedure. Participants were given the instructions on the screen as well as verbally by the experimenter. The experiment had a total of 168 trials grouped into two blocks; the ‘no retention’ block was always followed by the retention block. After the instructions for each block, subjects practised 8 trials. On each trial, a fixation stimulus was presented for one second in the center of a computer screen, followed by a word in lowercase white letters that remained for one second. After a 250 ms interval (blank screen) a target was presented (in uppercase yellow letters) that remained on the screen until a lexical decision was made. In the control condition, the next trial started after a 500 ms delay, whereas in the retention condition a question mark prompted the participant to recall the prime word. The experimenter recorded the recall. Participants got feedback whenever an error was made.

Results and discussion

The mean median reaction times and error rates for all conditions are presented in Table 1. Performance on naming the prime was at ceiling (100% correct), discounting an explanation based on some form of speed-accuracy trade-off. Because of the large differences in standard deviations between the control and the retention condition, log-transformed RTs were used in the analyses with the Retention-variable, while untransformed RTs were used in the pairwise within-block comparisons.

An overall ANOVA on the lexical decision times revealed a main effect of Retention [$F(1,19)=40.35$, $MSe=0.04$, $p<.001$] and a marginal effect of Relatedness [$F(2,38)=2.55$, $MSe=0.02$, $p=.091$]. The interaction did not reach significance. A similar ANOVA on the response accuracy only revealed a marginal effect of Relatedness [$F(2,38)=2.64$, $MSe=0.001$, $p=.084$].

Pairwise comparisons were conducted to specifically address the predictions made by the Controlled Center-Surround hypothesis. This analysis revealed that priming effects were only obtained for the strongly related prime-target pairs in the no-retention control condition both for RTs [$t(19)=2.48$, $p<.05$] and error rates [$t(19)=2.42$, $p<.05$].

Experiment 1 replicates the failure to obtain a priming effect when the prime word needs to be retained. Although several methodology-related explanations could be given for the absence of priming, the mere observation of a lack of priming due to an experimental manipulation begs further inquiry. One possibility for the lack of priming in the retention condition could be that participants were preparing the articulatory response while making the lexical decision. This could lead to a form of response interference, where both verbal and manual responses are prepared and executed. Therefore, Experiments 2 and 3 employed a recognition task on the prime word instead of a verbal response. It was hoped that this would ‘clean up’ the processes during the lexical decision.

Experiment 2

Participants. Twenty-four volunteers from the University of London participated in the experiment. All participants had English as their first language, were right-handed and had normal or corrected-to-normal vision.

Design. The experiment conformed to a 3 x 2 within-subject design, with Relatedness (unrelated, low-related, high-related) and Retention as independent variables. Lexical decision times and accuracy were measured.

Materials. 112 word pairs were selected from the MRC Psycholinguistic Database (Coltheart, 1981). The word pairs had a word frequency ranging from 10 to 660 per million (Kucera & Francis, 1967). The association strengths between the prime and target word ranged from 5.4 to 66.7 ($M=34.5$; Moss & Older, 1996). A median split divided the words in high and low association-trials. All words and pseudohomophones were one syllable long. Unrelated trials were formed by rearranging the related pairs. Each participant saw each word only once, but target words rotated across participants in all conditions.

Apparatus. The apparatus as in Experiment 1 was used.

Procedure. Participants were given the instructions on the screen as well as verbally by the experimenter. The experiment had a total of 224 trials grouped into two blocks; the ‘no retention’ block was always followed by the retention block. After the instructions for each block, subjects practised 8 trials. On each trial, a fixation stimulus was presented for one second in the centre of a computer screen, followed by a word in lowercase white letters that remained for one second. After a 250 ms interval (blank screen) a target was presented (in uppercase yellow letters) that remained on the screen until a lexical decision was made. In the control condition, the next trial started after a 500 ms delay, whereas in the retention condition a list of four words appeared (the prime and three distractors) and the participant had to indicate by pressing one of four keys which one was the prime word. Participants got feedback whenever an error was made.

Results and discussion

The mean median reaction times and error rates for all conditions are presented in Table 1. Performance on recognising the prime was at ceiling (99% correct) and did not show an effect of Relatedness.

An overall ANOVA on the (log-transformed) lexical decision times revealed a main effect of Retention [$F(1,23)=43.34$, $MSe=0.0056$, $p<.001$] and a main effect of Relatedness [$F(2,46)=11.61$, $MSe=0.004$, $p<.001$]. The interaction did not reach significance. A similar ANOVA on the response accuracy only revealed a main effect of Relatedness [$F(2,46)=3.97$, $MSe=0.001$, $p<.05$] and a marginal Retention x Relatedness interaction [$F(2,46)=2.59$, $MSe=0.001$, $p=.086$].

Pairwise comparisons revealed that priming effects were only obtained for the strongly related prime-target pairs in the no-retention control condition for RTs [$t(23)=3.90$, $p=.001$]. Priming effects in the error rates were

found for strongly related prime-target pairs in both Retention conditions [control: $t(23)=2.10$, $p<.05$; retention: $t(23)=2.40$, $p<.05$] and for weakly related prime-target pairs in the retention condition [$t(23)=2.81$, $p=.01$].

Experiment 2 replicates the findings of Experiment 1 in showing priming effects only in the control condition and only for the strongly related prime-target pairs. A between-experiment analysis further revealed that the reaction times between the two groups did not differ (all $ps>.15$), suggesting that the type of memory task did not have a noticeable impact on performance.

Given the possibility that the amount of priming is affected by the increased attentional focus, a Controlled Center-Surround hypothesis would have to predict that the off-surround component exerts more influence the more attention is paid to the prime word. It is therefore expected that at shorter SOAs, priming will be observed in the retention condition, even when the prime can be reported after the lexical decision. Experiment 3 tests this assumption.

Experiment 3

Thirty-two volunteers from the University of London participated in the experiment. All participants had English as their first language, were right-handed and had normal or corrected-to-normal vision. The design, materials and procedure were the same as in experiment 2, with the difference that the prime was presented for 250 ms and was immediately followed by the target.

Results and discussion

The mean median reaction times and error rates for both conditions are presented in Table 1. Performance on recognising the prime was at ceiling (98% correct) and did not show an effect of Relatedness. The data from one participant were excluded from the analysis due to extreme long RTs.

An overall ANOVA on the (log-transformed) lexical decision times revealed a main effect of Retention [$F(1,30)=75.14$, $MSe=0.06$, $p<.001$] and a main effect of Relatedness [$F(2,60)=8.15$, $MSe=0.005$, $p=.001$]. The interaction did not reach significance. A similar ANOVA on the response accuracy also revealed a marginal effect of Retention [$F(1,30)=3.51$, $MSe=0.002$, $p=.071$] and a marginal effect of Relatedness [$F(2,60)=2.62$, $MSe=0.001$, $p=.081$].

Pairwise comparisons revealed that, for RTs, priming effects were obtained for the strongly related prime-target pairs in both the control [$t(30)=3.46$, $p<.005$] and the retention [$t(30)=2.20$, $p<.05$] condition. Weakly related prime-target pairs showed a priming effect only in the retention condition [$t(30)=2.15$, $p<.05$]. Priming effects in the error rates were found only for strongly related prime-target pairs in the no-retention control condition [$t(30)=2.43$, $p<.05$].

Experiment 3 confirms the assumption that the mechanism responsible for the absence of priming in

Experiments 1 and 2 develops over time. Interestingly, in contrast to the findings with long SOA, with short SOA, the numerical values of the RT-priming effect are larger in the retention than in the control condition.

Table 1: Results of Experiments 1, 2 and 3. RTs in ms and proportion correct within brackets.

	Unrelated	Weak-related	Strong-related
Experiment 1 (N=20): recall + long SOA			
Control	606 (.95)	587 (.98)	576 (.98)
Retention	759 (.96)	769 (.98)	736 (.96)
Experiment 2 (N=24): recognition + long SOA			
Control	633 (.96)	631 (.99)	597 (1.0)
Retention	816 (.98)	828 (1.0)	788 (1.0)
Experiment 3 (N=31): recognition + short SOA			
Control	755 (.97)	741 (.96)	722 (.99)
Retention	1070 (.98)	1015 (.98)	1012 (.99)

General Discussion

The three experiments provided further insight into the observation that priming effects are absent when the prime word is actively maintained during lexical decision to the target. In all three experiments, reaction times in the retention condition were slower than in the standard control condition, which merely reflects the increase in cognitive demand in this dual-task situation. The effect of relatedness was only significant in Experiments 2 and 3, which employed a recognition task on the prime word. Although the interaction between Retention and Relatedness was not significant in any of the experiments, based on previous reports, pilot studies and the predictions from the Controlled Center-Surround hypothesis, pairwise comparisons revealed an interesting picture. With long SOA (1250ms), priming was only found for strongly related targets and only in the control condition, the *prime-retention effect*. With short SOA (250 ms), priming was found for weakly and strongly related targets in the retention condition and for strongly related targets in the control condition.

Although further studies are required to investigate this pattern in more depth, the present set of experiments already rules out two alternative explanations for the absence of a priming effect in the retention condition. First, in Fischler and Goodman (1978), Henik et. al. (1994) and Experiment 1, a verbal report had to be given after the lexical decision task. It is possible that the absence of semantic priming does not originate at a memory level, but instead may be due to some form of interference between executing the lexical decision and preparing the articulatory response for reporting the prime. However, the fact that the main results did not change when a recognition task was used instead of

a recall task, suggest that the *retention* of the prime and not the articulatory preparation of the prime was crucial. Second, Henik, et. al. (1994) suggested that the absence of priming in their experiment was due to the prime word being held at a shallow level of processing (e.g., phonological code) preventing “the needed attentional resources from being allocated at the semantic level” (p. 165). However, in the experiments reported here, the strength of the prime-target association modulated the effect. This also indicates that the *prime-retention effect* and the *prime-task effect* are different phenomena. The former requires full processing and active maintenance of the prime word, whereas the latter requires allocating attention away from the semantic level (but remaining within the same processing domain; Chiappe, Smith & Besner, 1996).

In awaiting more conclusive evidence, the current results support the proposal that the center-surround mechanism, which is assumed to be a structural component of the semantic memory system, dominates when more attention is directed to the prime word. In such situations prime-activation and activation-spread may trade off. To illustrate the Controlled Center-Surround hypothesis, consider Figure 1. In this figure, the strength of association between prime and target are set on the abscissa with the weakest strength to the right. On the ordinate the priming effect (RT_{unrelated} – RT_{related}) is set out for the long SOA (averaged over Experiments 1 and 2) and for the control and retention condition. The ‘priming effect’ for the ‘prime’ is a linear extrapolation of the values for the strong and weak associates. This figure makes two points. First, it makes the intuitive prediction that when the prime is in short-term memory, a decision on the prime itself is speeded up. Second, the overall pattern resembles the textbook example of an attentional on-center-off-surround ‘Mexican hat’ receptive field in the visual domain.

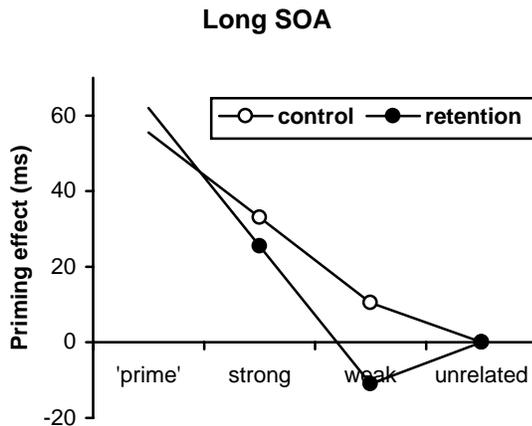


Figure 1: Priming effect as function of the strength of the prime-target association for *long* SOA. The values for the ‘prime’ are linear extrapolations from the values at strong and weak strength.

The figure for the short SOA is more complex (see Figure 2). The same prediction for identity priming is made, with larger ‘priming’ in the retention condition compared to control. However, the priming effect at short SOA seems larger in the retention condition than in the control condition. This pattern was replicated in a follow-up study (not reported here) and if this holds true in future studies, it would mirror the two-stage activation process proposed in the literature using homographs (words that have multiple meanings). In this two-stage process, an initial (automatic) activation of all meanings of a word is followed by a stage in which non-dominant or incongruent meanings are suppressed (Simpson & Burgess, 1985; Simpson & Kang, 1994). According to the hypothesis proposed here, the suppression in the second stage is a result of biased competition, where a deliberate directed attention to relevant word meanings makes them win this competition.

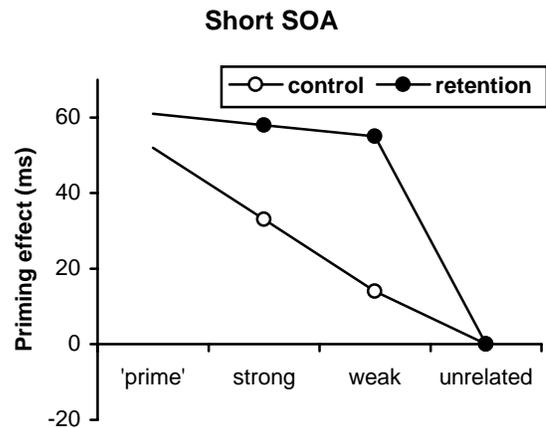


Figure 2: Priming effect as function of the strength of the prime-target association for *short* SOA. The values for the ‘prime’ are linear extrapolations from the values at strong and weak strength.

Although not predicted initially, the numerically larger priming effect with short SOA is not inconsistent with the Controlled Center-Surround hypothesis. The initial activation of the prime facilitates strong and weak related targets, but the inhibitory influence is only felt after the prime has received a large amount of activation (as is the case with long SOA). When the prime needs to be retained, the prime is activated very strongly, leading to larger priming effects for both weak- and strong-related targets at short SOA, but at long SOAs the off-surround component depresses both targets below the point where priming effects are obtained (or even a trend for a negative priming is observed). This attentional tuning on semantic concepts is only suggested by the presented dataset. A series of experiments are being prepared to address other methodological and theoretical issues. Nevertheless, the mere observation that the priming effect is modulated by short-term retention of the prime word poses interesting

constraints on existing and future computational models of priming.

The finding of a *prime-retention effect* motivates taking a closer look at the structure of semantic memory and the influence of controlled attention on its internal dynamics. Understanding these characteristics may provide valuable contributions to debates on the automaticity assumption of the spread of activation and resource limitations in language/cognitive processing. For example, an initial step in modelling the prime-retention effect (Davelaar, 2004), suggests ways to account for a variety of empirical findings on the interaction between attention and memory, such as hyperpriming in thought-disordered schizophrenic patients (e.g., Spitzer, et. al., 1993), individual differences in negative priming and presentation rate effects in false memory (McDermott & Watson, 2001).

Dagenbach and Carr (1994) proposed the Center-Surround hypothesis to account for the strategic carry-over effects in masked priming experiments. Here, the *prime-retention effect* suggests that (1) the center-surround mechanism can be observed in the behavioural data when attention is allocated to parts of the semantic system and (2) has a specific time-course. Future research, using the prime-retention paradigm, could provide detailed information on the structure of semantic memory and the temporal dynamics of the processes that control the spread of activation.

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