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### **Proceedings of the Annual Meeting of the Cognitive Science Society**

#### **Title**

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#### **Permalink**

<https://escholarship.org/uc/item/9fk111pr>

#### **Journal**

Proceedings of the Annual Meeting of the Cognitive Science Society, 23(23)

#### **ISSN**

1069-7977

#### **Author**

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#### **Publication Date**

2001

Peer reviewed

# Graded lexical activation by pseudowords in cross-modal semantic priming: Spreading of activation, backward priming, or repair?

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## Abstract

Spoken word recognition models treat mismatching sensory information differently. Mismatching information deactivates lexical entries according to one type of models. In another type of models, lexical entries are activated reflecting their degree of match with the input. This issue is mainly investigated with cross-modal semantic priming and lexical decision. This paradigm has been suspected of backward priming. I report three cross-modal priming experiments using naming and lexical decision to explore the sensitivity of word recognition to different degrees of match and to investigate the contribution of backward priming. Primes were pseudowords minimally (*\*baprika*) or maximally (*\*zaprika*) deviating from a word (*paprika*). A contribution of backward priming processes is likely. A repair of the mispronounced item as suggested by Marslen-Wilson (1993) seems untenable.

## Introduction

The tolerance of spoken word recognition to a wide variety of distortions, e.g. misarticulation, phonological processes, or masking by environmental noise poses a serious problem for spoken word recognition models. This problem is tied to the question of what constitutes a match or a mismatch. Certain distortions might not form a mismatch at a lexical level. A system intolerant even to minor mismatches seems unlikely given highly prevalent variation in articulation.

## Effects of Match and Mismatch

An account of mismatch effects has been formulated in Cohort (Gaskell & Marslen-Wilson, 1996; Marslen-Wilson, 1993). Gaskell and Marslen-Wilson (1996) found that primes with a legally place assimilated phoneme, e.g. *\*leam*<sup>1</sup>, are as effective as unaltered primes, e.g. *lean*, in cross-modal repetition priming. They suggest that only non-redundant, distinctive, and marked phonological information is coded in the lexicon. For instance, place of articulation is unspecified for coronals: [t],[d],[n],[s],[z]. Therefore, they can assimilate to different places of articulation and still do not form a mismatch at a lexical level (see Coenen, Zwitserlood, & Bölte (in press) for different observations).

Ignoring phonological underspecification, Connine, Blasko, and Titone (1993) found that minimally mismatching primes, e.g. *\*zervice*, accelerated lexical

decision to visual targets, e.g. *tennis*. Maximally deviating primes (e.g. *\*gervice*, > one phonemic feature) primed if they were made from rare words. Priming effects were graded by degree of mismatch. Connine et al. (1993) concluded that the word recognition system reflects the degree of featural overlap with the input thereby compensating for deviations. These findings are in conflict with observations by Marslen-Wilson (1993; Marslen-Wilson & Zwitserlood, 1989).

McClelland and Elman (1986) claim that Trace can compensate mismatching information. In Trace, activation spreads from a feature level to a phoneme level, and from there to a word level. Activation also spreads back from a word node to its constituent phonemes at the phoneme level. McClelland and Elman (1986) report that minimal mismatches are recognised, e.g. *\*bleasant* as *pleasant*. But simulations using the whole Trace lexicon showed that Trace does not recover easily from initial mismatches (Goldman, Frauenfelder, & Content, 1997 cited after Frauenfelder & Peters, 1998).

The pattern of results by Connine et al. (1993) can partly be captured by the Shortlist model (Norris, 1994). Input to this model consists of a string of phonemes. A list of words candidates, the Shortlist, is formed on the basis of bottom-up information. Mismatching information lowers the bottom-up support for lexical candidates, similar to the Cohort model. But Shortlist can overcome this reduction and activate the target to “a relatively high level of activation” (Norris, 1994, pp. 214). Bottom-up inhibition prevents activating the target if the mismatch is too large. Systematic simulations investigating the role of mismatching information are not yet available.

## Mismatch Repair

Marslen-Wilson (1993, Marslen-Wilson, Moss, & van Halen, 1996) interpreted the findings obtained by Connine et al. (1993) as a reflection of a repair process. According to this view, items like *\*zervice* are identified as mispronunciations of *service*. *\*zervice* activates *service* but to a degree insufficient for word recognition. The best fitting lexical entry is determined in a second pass. The target, e.g. *tennis*, might operate as a cue to the identity of the pseudoword. The repair mechanism is a subperceptual process that does not form a new perceptual experience. Marslen-Wilson et al. (1996) suggest that the influence of the repair mechanism is more evident at long interstimulus intervals (ISI) or long reaction-times (RT > 650 ms) because

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<sup>1</sup> Pseudowords are marked by an asterix.

processing time available for repair is increased.

### Contribution of Backward Priming

Cross-modal priming that is the presentation of an auditory prime accompanied or followed by a visual target was used in all studies mentioned above. This paradigm supposedly reflects backward and forward priming effects in lexical decision (Koriat, 1981; Tabossi, 1996). Backward priming refers to the observation that an association from target to prime in absence of an association from prime to target facilitates reactions.

The most unlikely mechanism for backward priming is expectancy generation. In expectancy generation, the prime is used to generate a set of potential targets. It is unlikely, that the pseudoword primes are used to generate the appropriate targets. One has to assume that the participants recognised the word the pseudoword had been made of and then they used this word to generate the appropriate target set.

At first, spreading of activation also seems to be an unlikely candidate because it is often assumed that the prime influences target processing before the target has been presented. Activation spreads from the prime to the target. Koriat (1981; Kiger & Glass, 1983) proposed that activation also spreads back from the target to the prime. This reactivation of the prime supports target processing. This mechanism requires that the pseudoword activated a lexical entry. Otherwise, there is no entry which could be reactivated by the target. Spreading of activation is restricted to short time frames and therefore predicts a reduction in priming at longer ISIs.

Backward priming is a post-lexical relatedness-checking mechanism according to Seidenberg, Waters, Sanders and Langer (1984). Only forward priming reflects spreading of activation. Lexical decision is especially prone to backward priming processes because of its sensitivity to post-lexical processes (Balota & Lorch, 1986; Neely, 1991). Participants check whether prime and target are related. If the check confirms this, a word answer is given. Chwilla, Hagoort, and Brown (1998) suggest that backward priming reflects post-lexical integration by a fast semantic matching mechanism.<sup>2</sup>

Peterson and Simpson (1989) found backward priming effects also for naming, but they were reduced relative to effects in lexical decision. The introduction of an 300 ms ISI reduced backward priming effects in naming even further while lexical decision was unaffected (Peterson & Simpson, 1989). The differential sensitivity of naming and lexical decision suggests that (backward) priming effects have a different origin in these tasks. Peterson and Simpson propose that backward priming effects reflect mainly lexical retrieval proc-

esses in naming but post-lexical bias in lexical decision.

In sum, naming is less influenced by backward priming than lexical decision. If backward priming effects are operative in naming, they reflect lexical retrieval processes. It is possible that research investigating mismatch effects registered backward priming effects because lexical decision has been used. The contribution of a repair mechanism is unclear.

### Experimental Issues

The research reported examines backward priming effects in cross-modal priming situations while manipulating the degree of mismatch. I was interested whether pseudowords mismatching lexical entries to different extents produce priming effects and how processes other than forward spreading of activation contribute to these effects. Similar to experiments mentioned above, degree of mismatch was manipulated in broad phonemic classes (voice, place, or manner) ignoring assumptions proposed by phonological underspecification. The contribution of backward priming or a repair mechanism was determined by manipulating the ISI of prime and target and by using lexical decision and naming as tasks. The latter manipulations make this study different from that of Connine et al. (1993).

Naming was used in Experiment 1 and 2. The target followed immediately at prime offset in Experiment 1. In Experiment 2 the ISI was 300 ms. A lexical decision task (LDT) was employed in Experiment 3. The ISI was 0 ms, 250 ms, or 750 ms.

### Materials and Pre-tests

The first two experiments employed the same materials and design. A subset of these materials were used in Experiment 3. A target was combined with five different spoken primes. For instance, the visual target *tomato* was either preceded by an semantically related prime, *paprika*, a pseudoword, *\*baprika*, that minimally deviates from the semantically related prime, or a pseudoword, *\*zaprika*, that maximally deviates from the semantically related prime. An unrelated word, *library*, or a pseudoword derived from the unrelated word, *\*nibrary*, served as controls. Minimal deviation means that the pseudoword's first phoneme differed in voice or place from the corresponding phoneme of the base word. A maximally deviating pseudoword differed in at least two phonemic classes from the base word. There were two within-factors: Prime-Target Relatedness (related vs. unrelated) and Prime Type (word, minimal, or maximal). ISI was varied between Experiment 1 and Experiment 2. In Experiment 3, ISI was a between factor for participants but a within factor for items. The experiments required evaluation of the semantic relatedness of prime and target (see Pre-test 1) and the determination that pseudowords were unequivocally perceived as pseudowords (see Pre-test 2).

**Pre-test 1** Potential targets (285 in total) were used

<sup>2</sup> Compound cue mechanisms of semantic priming come to similar predictions (Ratcliff & McKoon, 1988). They will not be considered here.

in a cross-modal priming experiment with a LDT. Primes were either semantically related or unrelated to the target. Targets were distributed over lists such that each target appeared only once per list. On list 1 a target  $n$  was preceded by its semantically related prime while target  $m$  was preceded by its control prime. Prime conditions of target  $n$  and  $m$  were exchanged on list 2. Pseudowords were added to have no-answers for the LDT. Targets were presented at offset of the auditory prime for 250 ms. RTs were measured from target onset for 1500 ms. All prime-target pairs, 197 in total, which attracted less than 50% errors and showed a priming effect larger than 0 ms were selected for Pre-test 2. Mean error percentage for word targets was 8.8%, 5.4% for the semantically related pairs and 12.0% for the unrelated pairs. The average priming effect was 78 ms ( $t(52) = 13.76, p < .001; t(196) = 18.81, p < .001$ ).

**Pre-test 2** The goal was to investigate whether a minimal pseudoword was unequivocally perceived as a pseudoword. In case a minimal pseudoword is missed, it is equal to its base word and priming might be amplified (Bölte, 1997). Minimal and unrelated control pseudowords were tested in an auditory LDT experiment along with 197 words serving as fillers. RT was measured as before. It was 941 ms for pseudowords and 865 ms for words. Twenty-one pseudowords attracting more than 20% errors were discarded as items for the following experiments. Further 26 pseudowords exhibiting the next highest error rates were excluded. There were 3% errors for minimal pseudowords and 2.6% errors for control pseudowords in the final item set of 75 prime-target pairs.

### Experiment 1: Cross-modal Priming Naming with an ISI of 0 ms

This cross-modal priming experiment aimed at investigating the role of mismatching information on lexical activation. There were 75 word targets (see Table 1). Each word target was combined with either a semantically related word, a minimally deviating pseudoword, a maximally deviating pseudoword, an unrelated word, or an unrelated pseudoword. Unrelated pseudowords were always maximally different. Fillers were added such that each prime-target combination was counter-balanced.

On each trial, the visual target was presented in capital letters for 360 ms at prime offset. Participants (63 in total) were instructed to name the target as fast and as accurately as possible.

Table 2 summarises the results of this experiment. Two participants were excluded because of technical failures. Latencies slower than 250 ms or faster than 1500 ms were discarded from the analyses.

Data were analysed using planned comparisons in form of one-sided paired  $t$ -tests. Priming effects were evaluated by comparing RTs of the related conditions with RTs of the unrelated conditions. This comparison

of RTs provides a measure of priming. Its magnitude can indicate the degree of lexical activation. Word primes facilitated naming responses by 19 ms ( $t(60) = 3.68, p < .001; t(74) = 18.97, p < .001$ ). Minimal (11 ms,  $t(60) = 2.73, p = .004; t(74) = 2.43, p = .009$ ) and maximal pseudowords (7 ms  $t(60) = 1.94; p = .03; t(74) = 1.72, p = .04$ ) were also effective primes.

Table 1: Primes of the target *tomato* as a function of conditions

prime type	word	minimal	maximal
		pseudoword	
related	paprika	*baprika	*zaprika
unrelated	library	*nibrary	

Word primes were more effective than minimal (7 ms,  $t(60) = 7.27, p = .017; t(74) = 6.91, p = .048$ ) or maximal pseudoword primes (10 ms,  $t(60) = 2.69, p = .005; t(74) = 2.48, p = .008$ ). There was no significant difference between minimal and maximal pseudoword primes (3 ms, both  $t < 1$ ). Thus, there is no gradation in lexical activation between minimal and maximal pseudoword as one observes with lexical decision. The overall smaller priming effect might prevent to distinguish between minimal and maximal pseudowords.

Table 2: Experiment 1. Mean RTs in ms, sd (in parentheses), and error percentages as a function of conditions.

prime type	word	minimal	maximal
		pseudoword	
related	489 (61)	496 (65)	499 (62)
	1.7%	2.6%	2.5%
unrelated	507 (69)	507 (61)	
	2.8%	2.1%	

Still, this finding replicates the one obtained by Connine et al. (1993). Minimal pseudowords and semantically related words prime naming responses. Similar to Connine et al. (1993), maximal pseudowords also show a priming effect. They are able to bring about semantic priming effects if made from rare words which was also the case in this study. The average base word frequency was 23/1 million (Celex, 1995).

There was a graded effectiveness with word primes being most effective. Minimal and maximal pseudowords were less effective than word primes. No further differentiation was possible.

### Experiment 2: Cross-modal Priming Naming with an ISI of 300 ms

This experiment used the same materials, design, and task as was used in Experiment 1. The ISI was 300 ms, however. The intention was to examine the effect of the ISI on semantic priming. It was shown previously that backward priming is reduced with such ISI in naming (Peterson & Simpson, 1989). In contrast, a longer ISI provides the repair process with more time available to

repair the deviating input. If it is operative, priming should increase, or, at least, it should not decrease.

There were 53 participants. One participant with more than 15% errors was excluded from the analyses. Data treatment was the same as before. Table 3 displays RTs, sd (in parentheses) and error percentages.

Table 3: Experiment 2. Mean RTs in ms, sd (in parentheses), and error percentages as a function of conditions.

prime type	word	minimal	maximal
		pseudoword	
related	437 (63)	440 (68)	444 (66)
	3.5%	3.5%	4.4%
unrelated	448 (75)	449 (71)	
	4.7%	2.1%	

There was significant priming with word primes (11 ms,  $t(51) = 1.944$ ,  $p = .029$ ,  $t(74) = 1.656$ ,  $p = .051$ ) and with minimal pseudoword primes in  $t(9)$  (9 ms,  $t(51) = 1.744$ ,  $p = .044$ ;  $t(74) = 1.391$ ,  $p = .084$ ). There was no priming for maximal pseudoword primes (both  $t < 1$ ). The conditions did not differ statistically from each other (word – min pw: 3 ms,  $t < 1$ ; word – max pw: 7 ms  $t(51) = 1.519$ ,  $p = .068$ ,  $t(74) = 1.162$ ,  $p = .125$ ; min pw – max pw: 4 ms, both  $t < 1$ ).

Semantic priming was reduced relative to Experiment 1 and only word and minimal pseudoword primes (in  $t(1)$ ) accelerated RTs. This finding does not support the repair mechanism suggested by Marslen-Wilson et al. (1996). If such process was operative, an increase in priming should have been obtained.

The activation of the target received via spreading of activation by the prime might have been reduced by “normal” decay when finally the target appeared. This resulted in the reduction of priming effects. The same argument also holds for backward priming via spreading of activation. When the target started to “reactivate” the prime, the prime’s activation was already decayed.

The following lexical decision experiment served to determine the contribution of specific backward priming accounts. Backward priming processes other than spreading of activation are less affected by long ISIs in lexical decision than in naming. Spreading of activation suffers in lexical decision from the same reduction as in naming (Neily, 1991; Seidenberg, et al. 1984).

### Experiment 3: Cross-modal priming with lexical decision

The rationale of this experiment was to investigate the influence of the ISI on semantic priming in a cross-modal lexical decision experiment. The ISI was 0 ms, 250 ms, or 750 ms. There were no maximal pseudoword primes here because semantic priming effects are most reliably obtained with minimal pseudowords (see Connine et al., (1993) or Experiment 2).

If there is no or only minor contribution of backward priming processes other than spreading of activation,

then priming should be reduced at longer ISIs. If the priming effects of pseudoword primes are due to a repair mechanism, priming should increase with longer ISIs.

The same targets and primes (words and minimal pseudowords) as before were used. In order to have no answers, pseudoword targets were added. Prime-target pairs were added such that Prime Type and Lexical Status of primes and targets were completely counter-balanced.

ISI was varied between participants. The visual target on which the participants had to perform a typical lexical decision task followed an auditory prime. Thirty-five participants were tested per ISI.

Two participants and two items were excluded because of high error rates (> 15%). See Table 4 for mean RTs, sd (in parentheses), and error percentages.

Table 4: Experiment 3. Mean RTs in ms, sd (in parentheses), and error percentages as a function of conditions.

ISI	prime type	lexical status	
		word	min pw
0	related	598 (84)	591 (70)
	unrelated	626 (76)	614 (77)
250	related	610 (70)	605 (96)
	unrelated	652 (96)	625 (88)
750	related	607 (105)	614 (108)
	unrelated	641 (108)	631 (108)
		3.2%	.8%
		4.7%	3.0%
		3.6%	4.2%
		4.7%	4.0%
		4.1%	1.6%
		6.9%	3.5%

ISI was a between factor in the participant analyses but a within factor in the item analyses. All other factors were within factors. The ANOVA yielded a significant result for the main effect Prime Type ( $F(1,100) = 83.409$ ,  $p < .001$ ;  $F(1,57) = 26.598$ ,  $p < .001$ ). Lexical decisions were faster for related prime-target pairs (605 ms) than for unrelated prime-target pairs (632 ms). The main effect Lexical status was also significant  $F(1,100) = 7.437$ ,  $p = .008$ ;  $F(1,57) = 4.265$ ,  $p = .043$ ). Word pairs (622 ms) were responded to slower than pseudoword pairs (613 ms). ISI was not significant in F1 ( $F < 1$ ) but in F2 ( $F(2,57) = 17.267$ ,  $p < .001$ ). RTs were faster when the target followed the prime (608 ms) immediately. The ISI of 250 ms or 750 ms delayed the RT by 15 ms or 16 ms, respectively. There was no significant interaction of ISI with any other factor. Only the interaction of Prime Type (related – unrelated) and Lexical Status (word – pw) ( $F(1,100) = 7.446$ ,  $p = .008$ ;  $F(1,57) = 4.003$ ;  $p = .050$ ) was significant. The RT obtained in the control conditions differed from each other (word: 639 ms, pw: 623 ms), while the RT in the related conditions did not differ

from each other (word: 605 ms, pw: 603 ms). The related conditions differed from the control conditions (Tukey HSD = 9.145,  $p = .05$ ). Put differently, the priming effect of the pw condition (20 ms) was smaller than that of the word condition (34 ms).

There is no reduction or any increase in priming across the three ISIs. Thus, no evidence was obtained for a repair mechanism as suggested by Marslen-Wilson et al. (1996). Rather, the stable priming pattern suggests that backward priming processes other than spreading of activation affect the semantic priming effect with pseudoword primes in LDT.

## Discussion

Semantic priming effects for words were obtained at all ISIs in all experiments independent of the task. They probably reflect a combination of forward spreading of activation and fast backward priming mechanism such as semantic matching (Chwilla, et al. 1998). Pseudoword primes behaved differently than word primes. They produced (1) smaller semantic priming effects than word primes, (2) they were sensitive to ISIs manipulations in naming but not in LDT.

Our results confirm the finding by Connine et al. (1993) that lexical entries are activated reflecting their degree of match with the input. Even maximal pseudowords are able to activate lexical entries if they are made from rare words. This supports the assumption that a perfect match is not required under certain conditions, e.g. low frequency (or low neighbourhood density?). The flexibility of the word recognition system towards deviations is greater than suggested in Cohort. It fits better to the assumptions formulated in Trace or Shortlist. This flexibility is astonishing because listeners often have to distinguish between minimal pairs. But the employed pseudowords are different from minimal pairs. They were “unique” by fitting best to one specific word, e.g. *paprika*, and not to several words. A word of a minimal pair also fits best to a specific lexical entry but it partly also fits to the other half of the minimal pair. This activation of two lexical entries might be sufficient to cancel out the flexibility observed for pseudowords. The better fitting lexical entry might inhibit the less well fitting one. It is also conceivable that the difference in activation is sufficient to discriminate between the two entries.

The consequences for the repair mechanism are described next. Then the priming mechanisms for naming and lexical decision are introduced and finally some adaptations for the models are outlined.

Marslen-Wilson and colleagues argued that the pseudoword prime activates a lexical entry to a low degree, but not sufficient for normal word recognition. That is, without the target *tomato* one would never recognise *paprika* given *\*baprika*. Supposedly, this recovery process takes time and is more evident in longer RTs (> 650 ms) or longer ISIs. ISI did not influence the size of the priming effect in lexical decision and RTs were

below this “critical” barrier. Thus, it is unlikely that the repair mechanism as suggested by Marslen-Wilson et al (1996) brought about the priming effects. Especially, the assumption that this process “kicks in” later in time does not fit to the data pattern.

The priming effects observed in naming can be a combination of forward spreading of activation and backward priming. They are reduced at longer ISIs because both, forward spreading of activation and backward priming, require a close temporal vicinity of prime and target (Kiger & Glass, 1983). A target presented before prime processing is complete, guides further processing of the prime and thereby influences the final representation according to this view. Notice, that a guidance of prime processing by a target requires that a pseudoword had activated a lexical entry. The smaller temporal overlap of prime-target processing results in a reduction in priming.

Priming effects were unaffected by ISI in the LDT experiment. Priming processes other than spreading of activation influences lexical decisions. Chwilla et al. (1998) showed that semantic matching contributes to priming effects over a range of ISI (0 ms – 500 ms). De Groot (1984, 1985) also postulates a fact-acting post-lexical meaning integration process. The word recognition system searches for a meaningful relationship whenever encountering words. A meaningful relationship between prime and target results in faster lexical decisions because a meaningful relation biases the participants to respond yes in LDT. Such process possibly hinders decisions to unrelated pairs because a failure to find a relation with the prime might bias a no response. That was exactly obtained. But semantic matching can only “form” a meaningful relationship if a prime activates lexical entries. Their degree of activation depend on the amount of phonological overlap with the prime. A semantic relation does not help to name a target more quickly, however. Apparently, semantic matching influences lexical decision more than naming.

To summarise, the present experiments show that pseudowords are able to bring about semantic priming effects. The priming effects are either a consequences of spreading of activation and fast-acting post lexical integration processes. The proposed backward priming mechanism requires the activation of a lexical entry by the prime. Also, pseudowords activate lexical entries according to their degree of overlap.

The models introduced above rely on spreading of activation for explaining semantic priming effects. Post-lexical integration is not implemented in any of the models. I present three reasons for this shortcoming. First, these models were not intended to cover situations in which a meaningful relationship between two words is formed. However, humans look for meaning most of the time. Second, the models miss capabilities to explain flexible task dependent behaviour. Lexical decision and naming as tasks are treated alike by the models. Task dependent capabilities are needed for

covering the findings. Third, post-lexical processes are often understood as task dependent processes in form of a “strategic” adaptation. As such, these processes do not inform about word recognition but rather about “strategic” adaptations. This conception is adequate if the “strategic” processes are under conscious control. But semantic integration is a fast unconscious process (Chwilla et al., 1998, De Groot, 1984, 1985).

Trace, Shortlist, or Cohort describe how semantically related entries influence word recognition in a spreading of activation manner. A situation in which two semantically lexical entries are activated at the same time and form a meaningful relationship, is not taken care of. Two lexical entries are mostly treated as competitors for word recognition. But word recognition can benefit of two simultaneously activated entries, especially given an imperfect input.

### Acknowledgements

Part of this research was supported by a grant, BO 1479 / 3-1, of the German research foundation (DFG, Bonn) awarded to Jens Bölte. Thanks go to Pienie Zwitserlood for her support. Heidrun Bien, Gregor Weldert, and Vanessa Mense were so kind to test the participants.

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