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Rapid Activation of the Lexicon: A Further Investigation with Behavioral and Computational Results

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Priming effects were observed in a categorization task for both prime–target synonym pairs (e.g., *boat–ship*) and first-associate pairs (e.g., *boat–sea*). However, the amount and onset of priming were different for synonyms and associated pairs. The effect appeared sooner for synonyms (at prime duration of 43 ms) than for associated words (57 ms onset) but was present for both these relationships at 71 ms of prime presentation. A prime visibility pretest was conducted with the same participants in order to determine the rate of recognition of our prime words. Last, a French matrix of the HAL model was built, which showed that synonyms pairs were semantically closer than associated pairs. These results are in accordance with our previous study (Frenck-Mestre & Bueno, 1999) and are discussed in relation with semantic models, such as Plaut's (1995) distributed model.

Key Words: semantic priming; synonyms; associative relatedness; semantic categorization; prime visibility.

The semantic priming effect has been widely explored and discussed since its original demonstration in the early 1970s (Meyer & Schvaneveldt, 1971; Meyer, Schvaneveldt, & Ruddy, 1972). This effect is that a target string of letters will be recognized as being a word more rapidly (for instance, *doctor*) if preceded by a semantically related prime word (e.g., *nurse*) than if not (e.g., *horse*). Important questions are, first, whether this effect is controlled by associative or by semantic relationships (cf. Lupker, 1984; McRae & Boisvert, 1998; Ratcliff & McKoon, 1988; Shelton & Martin, 1992; Thompson-Schill, Kurtz, & Gabrieli, 1998); second, to determine what the onset of this effect is (Fischler & Goodman, 1978; Frenck-Mestre & Bueno, 1999; Plaut, 1995); and third, to determine which task is the most appropriate task for the study of semantic memory (cf. Frenck-Mestre & Bueno, 1999; Grainger & Frenck-Mestre, 1998; McRae & Boisvert, 1998). The present study investigated two different types of relationships between a prime and a target word (associative and synonym) under three different brief delays of prime presentation (43, 57, and 71 ms). This study is an extension of our previous study (Frenck-Mestre & Bueno, 1999), in which we found that masked priming produced reliable facilitation in a categorization task for a semantic nonassociative relationship (e.g., *bus–subway*) but not for a semantic

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associative relationship (i.e., pairs made up of strong associates which were category coexemplars, such as *dog–cat*). Priming for associated prime–target pairs was only observed at longer prime exposures in this task.

The first model to explain semantic priming was the ‘‘Spreading Activation model’’ developed by Collins and Loftus (1975). According to this model, each concept stored in memory is represented by a discrete node in a network. Each node is semantically and/or associatively linked to other nodes. The strength of a link would depend on the semantic distance between concepts. When a concept is processed, it would be activated itself and would then cause a spread of activation toward other linked concepts.

An alternative model was proposed by Ratcliff and McKoon (1988). According to these authors, when two words are successively and rapidly presented, their combination creates a ‘‘compound cue’’ that will be compared in long-term memory to already stored relationships. If a match is found between the pair of identified words and a representation stored in memory, then processing is quicker as compared to when no match is found. For a pair to exist in long-term memory it must have been encountered several times. This is the case for associative relationships but not necessarily for semantic (nonassociative) relationships. Note, however, that significant priming has been demonstrated both for semantic relationships (Fischler, 1977; Frenck-Mestre & Bueno, 1999; McRae & Boisvert, 1998) and for mediated pairs such as *tiger–stripes* (McNamara & Altarriba, 1988). This model also supposes that the priming effect must be tied to a relatively late process because, in order to be constructed, the compound cue must process both the prime and the target word. Given such, we should not find priming when the prime word is presented too briefly to be systematically identified, as the prime word must be identified to construct the compound cue. Indeed, Ratcliff and McKoon (1988, p. 398) specifically stated that ‘‘at very short SOAs (50 ms) between prime and target, it is assumed that the prime is not registered sufficiently in short-term memory to enter the compound cue. . . .’’ Moreover, these authors demonstrated just that.

The models that can account for semantic priming are now tending toward distributed connectionist models (Cree, McRae, & McNorgan, 1999; Masson, 1995; Plaut, 1995). These models integrate a plainly more semantic component, which was perhaps lacking in the earlier models of semantic memory (Collins & Loftus, 1975; Ratcliff & McKoon, 1988). In the framework of these models, each concept has an activation pattern made up of semantic features. The more semantically close two concepts are the more similar their patterns are, thus the quicker it is to transit from one to the other.

Plaut’s (1995) recent simulation is of great interest to the present study. Plaut compared two types of relationships between a prime and a target word: an associative relationship (e.g., *butter–bread*) and a semantic relationship (e.g., *bread–cake*). In his simulation, the results showed an early priming effect for the semantic relationship which decreased as prime duration increased. This follows from the distributed approach, as the more the prime is instantiated, the less its pattern resembles that of the target word. Inversely, with the associative pairs, the priming effect increased with prime duration. Here, the similarity of the patterns is not the cause of the priming effect. A learning mechanism explains this priming effect: The system learns to move rapidly from one pattern to another based on the learned co-occurrence of these patterns.

A fourth type of model can be distinguished in the study of the semantic memory: models based on the co-occurrence of lexical items inside a corpus (Lund, Burgess, & Atchley, 1995; Lund & Burgess, 1996; Lund, Burgess, & Audet, 1996; Burgess & Lund, 2000, with the HAL model; Landauer & Dumais, 1997, with the LSA model).

In these models, semantic similarity is calculated from semantic vectors: Two words that appear in similar contexts will have similar vectors and a higher semantic similarity than words that occur in distinct contexts.

Herein, we focused our attention on a newly developed French matrix using the HAL model. In its original English version, this model combined a 160-million-word corpus (but reduced to the 70,000 most frequently occurring words) taken from Usenet (all newsgroups containing English dialog were included) and was initially used to track lexical co-occurrences in a 10-word moving window.[1] The goal of this model is to build a matrix where it will be possible to calculate semantic vectors for each word and then the semantic distance between them [this semantic distance is given in ‘‘Riverside Context Units’’ (RCUs), which are completely arbitrary, after a normalization of the vectors] as well as the probability of co-occurrence of two words in a given corpus. Two words are said to co-occur when they appear in the same 10-word moving window, run over the entire corpus. From this, values of co-occurrence are calculated and used to build the matrix (a high-dimensional space) with the whole vocabulary on its axis (70,000 words in columns and 70,000 words in rows).[2] By combining the data from a word’s row and column, a sparsely populated vector of 140,000 elements is formed for a given word. One can then compare the vectors of every single word to every other word in the corpus. The more the vectors of two words are similar, the closer they are semantically.

The French version of the HAL model is currently in the making (Bueno, Frenck-Mestre, Burgess, & Lund, 2000). The procedure used is exactly the same as in the English version. It presently contains a corpus of some 20,000 words, based on French Usenet groups; however, it will be augmented and extended to include French scripted material (the French newspaper *Le Monde*) in the near future. The corpus is thus somewhat limited at present, as it primarily contains rather high frequency words and is as yet still too small to produce truly reliable estimates. The present work with this model is thus to be taken as an indication of semantic similarity and not as a precise measure.

Our experiment enabled us to confront these different models. We used a categorization task, for which participants had to decide whether the presented item (the target word) was an abstract or a concrete word, since several studies have shown the efficiency of this kind of task in the study of semantic memory (Frenck-Mestre & Bueno, 1999; Grainger & Frenck-Mestre, 1998; McRae & Boisvert, 1998). We used an associative nonsynonymy relationship and a synonymy nonassociative relationship. Indeed, synonyms seem to be good semantic candidates in that they share a maximum of semantic features and hence should provide large priming effects. Although, we did not calculate the semantic overlap between synonyms, as did McRae, De Sa, and Seidenberg (1997) with another type of semantically related words, we could easily project that pairs such as *boat–ship* or *glass–cup* will have a greater semantic overlap than *boat–sea* or *glass–water* since they belong to the same semantic category. Since one of our aims, in our experiment, was to deal with automatic priming, three short delays of prime presentation were used (43, 57, and 71 ms).

The simulation of Plaut (1995) showed an early priming effect for semantically related words and a later effect for associatively related words. This pattern of results was tested in our experiment. We predicted, in our behavioral research, priming effects for words sharing semantic features (i.e., synonyms) as demonstrated in our former study (Frenck-Mestre & Bueno, 1999). This effect should appear from the

[1] The latest version of this model includes 320 million words (Burgess & Lund, 2000).

[2] The nonwords and postheaders are not a problem in this model since the data reduction, from the whole corpus to the 70,000 most frequent words, extracts extraneous information and nonword symbols.

shortest delay of prime presentation and decrease as soon as the prime word is systematically recognized by participants. Conversely, the priming effect for the associated words should occur later and reach an asymptote threshold as soon as the prime word is systematically recognized.

In accordance with the HAL model, we can predict that associated words are more likely to be contiguous in a 10-word window than synonymous words. In contrast, the ''semantic distance'' as estimated by RCUs should be shorter for synonyms than for associated words. To determine the above, we calculated the semantic distance between the words in each pair as well as the probability of co-occurrence of the words in a 10-word moving window by running them through the French HAL matrix. Note, however, that these measures are but indications, given the relative rough status of the French corpus at present.

EXPERIMENT

Method

Participants. Forty-eight students from the Université de Provence, 20.5 years old on average, took part in the experiment, which lasted roughly 30 min, for course credit. They all were in their first year of psychology and were not familiar with the semantic priming paradigm prior to participating in the experiment.

Material and design. The material was made up of 40 prime–target pairs (20 first-associated pairs according to published norms, Ferrand & Alario, 1998; and 20 nonassociated synonyms from a French synonym dictionary, Boussinot, 1981; cf. Appendix 1). Each prime word instantiated an associative and a synonym target (the prime *boat* instantiated *sea* as an associative target and *ship* as a synonym target). All the words were concrete. Neutral conditions were created by matching prime words with words of the same length and frequency, but which bore no relationship to the targets. The 20 prime words varied in length from 4 to 9 letters ($M = 6.3$; $SD = 1.56$) and in frequency from 0.51 to 196.42 occurrences per million ($M = 41.6$; $SD = 54.30$; BRULEX). The 20 associated targets were from 3 to 10 letters long ($M = 5.8$; $SD = 2.04$) and their frequency was from 0.63 to 892.10 occurrences per million ($M = 151.21$; $SD = 215.97$). The 20 synonym targets were 5 to 9 letters long ($M = 6.8$; $SD = 1.23$) and had a frequency ranging from 0.21 to 51.81 occurrences per million ($M = 10.49$; $SD = 14.04$). There was a significant difference in the mean frequency of the two target populations [$F(1, 38) = 9.44$, $p < .003$]; however, this difference in average frequency was not considered to be a problem for two reasons. First, Forster and Davis (1984) demonstrated that there is no effect of frequency on priming in the masked priming paradigm. That is, the amount of priming is equal for low and high frequency words despite the longer overall RTs for low frequency words. Second, we (Frenck-Mestre & Bueno, submitted) have shown that differences in priming for semantically related as opposed to associatively related pairs are linked to *task demands,* not to the frequency of the prime or target words. For both of the above reasons, we did not consider the frequency difference in and of itself to predict differences in priming facilitation.

Four lists were created, each including 5 pairs of associated related pairs (e.g., *boat–sea*) and 5 associated unrelated pairs (e.g., *milk–sea*), 5 synonymous related pairs (e.g., *boat–ship*) and 5 synonymous unrelated pairs (e.g., *milk–ship*). Added to these 20 pairs of critical trials were 30 pairs of fillers. The fillers were created in order to make the task a categorization task. Half the targets of a list were ''concrete'' words and the other half ''abstract'' words. Five of these 30 pairs of fillers had neither a lexical nor a semantic relationship but required a ''concrete'' response to the target word; 10 pairs had a relationship between prime and target and required an ''abstract'' response; 10 pairs had no relationship between the prime and the target but required an ''abstract'' response; 5 pairs had a relationship but, however, required an ''abstract'' response (thanks to these 5 pairs, the participant could not judge the concreteness of a word only on the ground of the presence of a relationship between the prime and the target; cf. Shelton & Martin, 1992, for instance). Three delays of presentation of the prime word were used (43, 57, and 71 ms; that is, three, four, and five screen rasters). Each participant was randomly assigned to one of the four lists at one of the three delays of prime presentation according to a Latin square.

Procedure. The participant was invited to sit in front of a 14″ CRT screen. S/he was told that s/he would see words, one by one, in the middle of the screen. Each sequence of words was as follows: A 500 ms forward mask made up of 11 ''#'' marks was first presented on the screen, followed by prime word for 43, 57 or 71 ms according to the condition of prime presentation (prime duration was blocked) and a backward mask made up of 11 ''#'' marks which lasted 14.2 ms (one screen raster); finally, the target word was presented on the screen and remained until the participant's response. A new sequence began 2000 ms afterward. The participant was invited to press, as quickly as possible, on a marked key of the keyboard if the word was a concrete word and on another marked key if the word was an abstract word. We insisted on the rapidity and accuracy of the responses. None of the participants were told about the presence of prime words.

A prime visibility posttest was created in order to look at the influence of the visibility of primes on the effective priming effect at our three different delays. Therefore, at the end of the experiment, participants were told about the presence of prime words in the experiment they just had participated in. They were again presented the list, but were to focus on the prime word and not on the target. Their task was to report the prime words that appeared before target words by typing them on the keyboard. The presentation of sequences was identical to the main experiment except that they had to type the prime word and not respond to the target word. No time restriction was given to achieve this task. The results of this posttest of visibility are presented in Table 1.

Results

Behavioral results. Two ANOVAs were conducted on response times (for correct responses) between 300 and 1000 ms, one with participants and one with items as sources of variance. Semantic Relationship (Associated vs Synonym) and Relatedness between the prime and the target (Related vs Nonrelated) were within-subject factors while Delay of prime presentation (43, 57, and 71 ms) was a between-subject factor. Table 1 summarizes the responses times and Fig. 1 the evolution of priming according to these three different factors.

Analyses showed main effects of Semantic Relationship [$F1(1, 45) = 71.60$, $p < .000$; $F2(1, 38) = 32.24$, $p < .000$] and Relatedness [$F1(1, 45) = 8.88$, $p < .004$; $F2(1, 38) = 5.85$, $p < .02$]. No other effect was observed except an interaction between the factors Delay of prime presentation and Relatedness in the item analysis [$F1(1, 45) = 1.75$, *ns;* $F2(2, 76) = 3.19$, $p < .05$].

Independent analyses were conducted on the data obtained for the two types of prime–target relationship (associated vs synonyms). For the synonyms, we observed a main effect of Relatedness [$F1(1, 45) = 8.33$, $p < .006$; $F2(1, 19) = 7.85$, $p < .01$], which did not interact with Delay of prime presentation (Fs < 1). For the associated words, no main effects were observed. However, there was a trend to an interaction between the factors Delay of presentation of the prime and Relatedness in the subject analysis and a significant effect in the item analysis [$F1(1, 45) = 2.41$, $p < .10$; $F2(1, 38) = 3.91$, $p < .03$]. The latter result led us to perform planned comparisons on this interaction. We compared the priming effects of the two longest Delays of prime presentation (57 and 71 ms) with the shorter delay (43 ms). This comparison is further justified by the results of the prime visibility test, indicating greater (and close) recognition rate of the prime words at the 57 and 71 ms delays than at 43 ms [$F1(1, 45) = 20.19$, $p < .001$]. The planned comparison showed a trend to the interaction in the subject analysis and a significant effect in the item analysis [$F1(1, 45) = 2.85$, $p < .10$; $F2(1, 19) = 9.75$, $p < .005$]. The facilitation produced by prime words tended to be greater at the two longer delays as compared to the shortest delay. Moreover, the comparison of priming at the shortest delay (43 ms) compared to the longest delay (71 ms) was highly significant [$F1(1, 30) = 4.21$, $p < .05$; $F2(1, 19) = 7.70$, $p < .01$].

HAL results. The results of the modelization indicate that in the French matrix synonym pairs are closer according to an Euclidean distance measure of their vectors than are associated pairs. That is, the distance between the vectors for two synonyms was numerically smaller than that between two associated words. For unrelated pairs, the numerical distance between the vectors for two words was highly similar for the associated and synonym targets. As such, the amount of ''priming'' predicted by the model should be greater for synonym pairs than for associated pairs, in line with our

TABLE 1

Summarization of the Response Time (with Means in Milliseconds, Percentage of Errors, and Standard Deviations) and Priming Effect According to the Factors Semantic Relationship, Relatedness, and Delay of Prime Presentation

	Associated related	Associated unrelated	Priming effect	Synonym related	Synonym unrelated	Priming effect	Prime visibility
	694	684	−10	744	766	+22	
43 ms	(1.25)	(2.5)		(7.5)	(2.5)		10.8%
	92	116		99	101		
	670	681	+11	729	766	+37	
57 ms	(2.5)	(0)		(2.5)	(5)		37.1%
	59	43		54	64		
	641	690	+49	731	772	+41	
71 ms	(1.25)	(6.25)		(10)	(0)		41.3%
	70	73		85	93		

Note. A plus sign indicates a positive amount of priming, a minus sign a negative amount of priming.

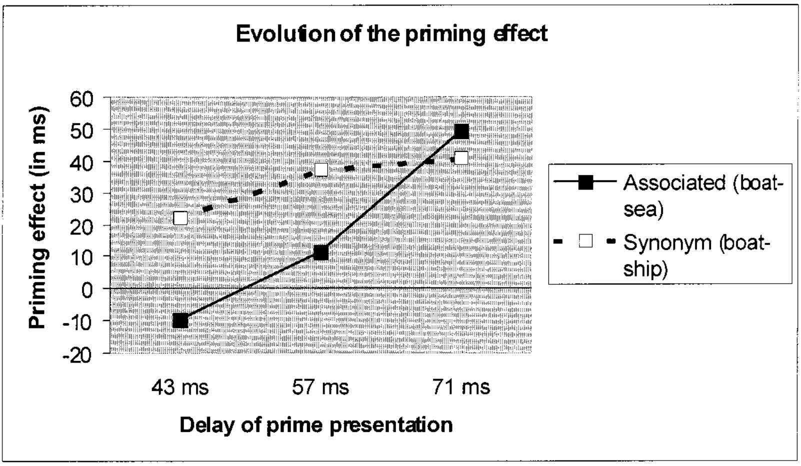

FIG. 1. Evolution of the priming effect according to the Delay of prime presentation (43, 57, and 71 ms) and to the Semantic Relationship (Associated vs Synonym).

behavioral results showing a rapid onset of priming for synonym pairs compared to a later onset for associated pairs. The mean semantic distances from the French HAL matrix are provided in Fig. 2.

In addition, we calculated the probability of co-occurrence of two words in the matrix as a function of type of relationship. The results indicated that associated words were more likely to be contiguous in a 10-word window (57% probability) than were synonymous words (25% probability) (Fig. 3).

DISCUSSION

The present results are in accordance with our former study (Frenck-Mestre & Bueno, 1999). We reproduced an early priming effect (starting at 43 ms of prime presentation) with semantically related words (synonyms) and a later effect with first associates (the magnitude of the effect began to be reliable around 57 ms of prime presentation).

Moreover, these results replicate the simulation-based results of Plaut (1995). Our

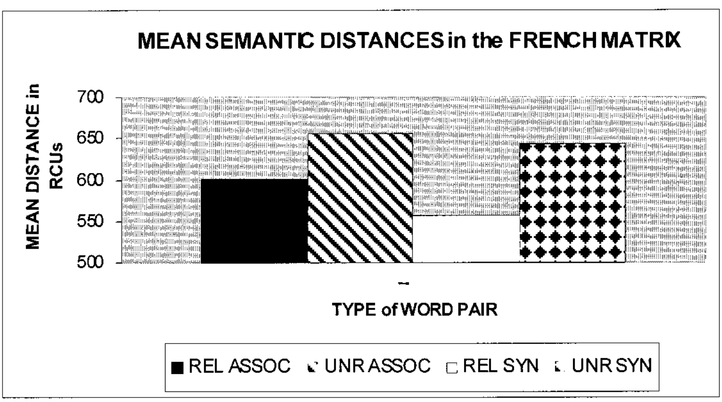

FIG. 2. Measure of the semantic distance in the French matrix as a function of the Semantic relationship (Associated vs Synonymous) and Relatedness (Related vs Unrelated).

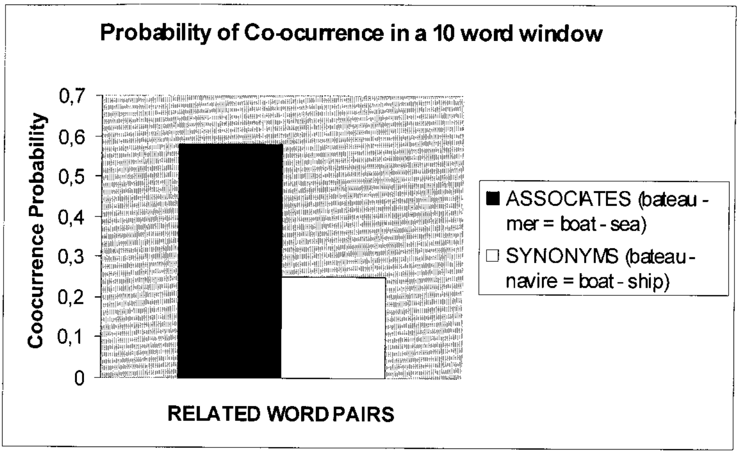

FIG. 3. Probability of co-occurrence of the related word pairs in a 10-word window for the associates and synonyms.

semantically related pairs began to produce a priming effect earlier (as soon as 43 ms) than associated pairs. The effect with synonyms did not decrease as predicted by Plaut's model with our longest delay of prime presentation (71 ms). On one hand, we can then suppose that 71 ms of prime presentation is not sufficient to produce a dissimilarity between the pattern of the prime word and the pattern of the target word for synonym pairs of words. One the other hand, this delay seems to indicate the beginning of robust priming effect with associated words. According to these results, automatic semantic priming occurs very early with semantically related words (even at a subliminal delay of prime presentation), whereas this effect appears later with associated words. Nowadays, one of the most important questions is to know if semantic priming is controlled by associative relationships (Shelton & Martin, 1992; Ratcliff & McKoon, 1988) or by semantic relationships (McRae & Boisvert, 1998; Cree, McRae, & McNorgan, 1999). Our results, as well as Plaut's results, reconcile these two different points of view. At the earliest level of processing, when around 10% of primes can be identified, semantic memory can be activated only with semantically related pairs (synonyms in this experiment). When the prime words begin to be more easily recognizable, the activation of semantic memory can be established with two types of relationship: associated words sharing a relatively low number of semantic features and synonyms with a more important semantic overlap. We can suppose that with longer delays of prime presentation (when the prime can be systematically identified) the pattern of results will be even more different. According to Plaut (1995), the priming effect obtained with associated words should reach an asymptote threshold when the effect with semantically related words should decrease.

What can be said, from our results as concerns the relationship between priming facilitation and the identification of the prime words? We can cite two studies that found semantic priming effect with a weak report of primes. First of all, Grainger and Frenck-Mestre (1998) found, in a bilingual paradigm, significant priming for translations (e.g., *chien–dog;* i.e., for pairs with a high semantic overlap) in a semantic categorization task as soon as 29 ms of prime presentation where only 1% of prime words were recognized in a posttest (the rate of report was 29.3% with 43 ms of prime presentation). Second, Hirshman and Durante (1992) used an interleaving procedure, that is, participants had to either report the prime or respond to the target within the same list. Their prime visibility was 5% at 33 ms of prime presentation and 43% at 50 ms of prime presentation (conditions where they obtained significant priming effects). It thus seems that the visibility of the prime is not a prerequisite for obtaining priming as Ratcliff and McKoon (1988) suggested.

The HAL simulation of our material sheds some light on the semantic nature of our pairs. Indeed, the French matrix developed in the framework of this model indicated differences between the two types of relationships we used. As expected, synonyms were semantically closer than associated words when we looked at their vectors, whereas the co-occurrence of words was greater for associated words than for synonyms. Despite the attractiveness of these data, however, we must insist upon the preliminary nature of these results. While they certainly are in accordance with results previously obtained in English (cf. Lund, Burgess, & Atchley, 1995; Lund, Burgess, & Audet, 1996), the database in French is currently not substantial enough to make any strong claims. Future work, with a larger data base will provide the basis for more precise predictions and experimental results.

In conclusion, a word can be said from our data about early priming. While a handful of studies have shown priming facilitation under very short (less than 50 ms) prime durations (Beauvillain & Segui, 1983; Fischler & Goodman, 1978; Simpson & Burgess, 1985) this does not appear to be the general rule. Recently, Grainger and Frenck-Mestre (1998) and Frenck-Mestre and Bueno (1999) obtained priming facilitation under masked, very rapid prime durations, with tasks that tap semantic processing better than lexical decisions. These studies and our study presented herein should lead to a reconsideration of the use of lexical decision tasks in the framework of semantic priming.

APPENDIX

Prime	Associative target	Synonym target
Barrière (barrier)	Clôture (fence)	Palissade (palisade)
Bateau (boat)	Mer (sea)	Navire (ship)
Boîte (box)	Allumettes (matches)	Coffre (chest)
Poivron (bell pepper)	Légume (vegetable)	Piment (pepper)
Canapé (sofa)	Lit (bed)	Divan (divan)
Casserole (saucepan)	Cuisine (kitchen)	Marmite (pot)
Chaussure (shoe)	Pieds (feet)	Soulier (shoe)
Bague (ring)	Doigt (finger)	Anneau (ring)
Crocodile (crocodile)	Dents (teeth)	Caïman (cayman)
Eglise (church)	Clocher (steeple)	Chapelle (chapel)
Rame (oar)	Bateau (boat)	Pagaie (paddle)
Tente (tent)	Camping (camping)	Chapiteau (marquee)
Couteau (knife)	Fourchette (fork)	Canif (penknife)
Verre (glass)	Eau (water)	Gobelet (cup)
Veste (jacket)	Pantalon (trousers)	Anorak (anorak)
Fenêtre (window)	Porte (door)	Hublot (porthole)
Gant (glove)	Main (hand)	Moufle (mitten)
Marteau (hammer)	Clou (nail)	Maillet (mallet)
Panier (basket)	Osier (osier/wicker)	Corbeille (basket)
Timbre (stamp)	Lettre (letter)	Vignette (vignette)

Note. Test words with their translation in English.

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