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ORIGINAL ARTICLE

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The effects of associative and semantic priming in the lexical decision task

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Abstract Four lexical decision experiments were conducted to examine under which conditions automatic semantic priming effects can be obtained. Experiments 1 and 2 analyzed associative/semantic effects at several very short stimulus-onset asynchronies (SOAs), whereas Experiments 3 and 4 used a single-presentation paradigm at two response-stimulus intervals (RSIs). Experiment 1 tested associatively related pairs from three semantic categories (synonyms, antonyms, and category coordinates). The results showed reliable associative priming effects at all SOAs. In addition, the correlation between associative strength and magnitude of priming was significant only at the shortest SOA (66 ms). When prime-target pairs were semantically but not associatively related (Experiment 2), reliable priming effects were obtained at SOAs of 83 ms and longer. Using the single-presentation paradigm with a short RSI (200 ms, Experiment 3), the priming effect was equal in size for associative + semantic and for semantic-only pairs (a 21-ms effect). When the RSI was set much longer (1,750 ms, Experiment 4), only the associative + semantic pairs showed a reliable priming effect (23 ms). The results are interpreted in the context of models of semantic memory.

Introduction

Since the pioneering study of Meyer and Schvaneveldt (1971), a large number of studies have shown that a target word (e.g., NURSE) is responded to more rapidly/accurately when it is preceded by an associatively/semantically related word (e.g., doctor) than when it is preceded by an unrelated word (screen). Although knowledge of "context" effects is important for understanding the structure and organization of the mental lexicon, the mechanisms responsible for these effects are still far from being well understood (see Lucas, 2000; McRae & Boisvert, 1998; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995, for recent reviews).

One factor that has contributed to the lack of a comprehensive model of context effects is the confounding between associative relations (as measured by word association norms, e.g., cradle-BABY) and purely semantic relations (e.g., as measured by the number of shared semantic features, or any kind of meaning relation, e.g., horse-ZEBRA). Despite the fact that separate accounts for automatic associative and semantic priming effects have been proposed in the literature (Chiarello, Burgess, Richards, & Pollock, 1990; de Groot, 1990; Fodor, 1983; Lupker, 1984; Plaut, 1995), many of the previous studies have used pairs that were both semantically related and normatively associated (e.g., doctor-NURSE). If priming only occurs automatically for associatively related pairs, as suggested by Shelton and Martin (1992; see also Lupker, 1984), priming would tap word form rather than word meaning. (Automatic processes are assumed to tap lexical-internal processes without being influenced by participants' strategies, see Neely, 1977.) Thus, associative priming effects could arise from spreading activation of a small subset of highly related items along the lexical network – possibly via co-occurrence in language – independently of the type of semantic relation between the prime and the target (see Balota & Paul, 1996; Fodor, 1983; Lupker, 1984; Plaut, 1995). In contrast, if automatic priming only occurs for semantically related pairs (see Maxfield & Chiarello, 1996; Thompson-Schill, Kurtz, & Gabrieli, 1998), priming would directly tap word meaning. In this context, automatic semantic priming could be considered as arising from spreading activation between concepts – either word nodes or "functionally unitized" items – that share similar features in semantic memory (Chiarello et al., 1990; Collins & Loftus, 1975; McRae &

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Boisvert, 1998; Plaut, 1995; Thompson-Schill et al., 1998).

To disentangle the effects of associative and semantic priming, it seems convenient to examine the priming effect for pairs of words that are both associative and semantically related as well as the priming effect for pairs of words that are semantically but not associatively related. Associatively related word pairs have ordinarily been defined in terms of word association norms: two words are associatively related when a large percentage of people give the target as the first word they think of in response to the prime in a free association task. Although associative prime-target pairs are ordinarily semantically related (e.g., doctor-NURSE), the argument has been made that associative relations arise not from semantic similarity per se but rather from co-occurrence in speech or in text (see Fischler, 1977; Fodor, 1983; Lupker, 1984; McKoon & Ratcliff, 1992). In contrast, many semantically related word pairs are not associatively related (e.g., truck-VAN). Although there is no general consensus with respect to the definition of a "semantically related" pair (see, for instance, McRae, de Sa, & Seidenberg, 1997; Moss et al., 1995; Neely, 1991), many of the previous studies have used members of the same semantic category (i.e., category coordinates; pig-HORSE) as semantically related pairs. However, synonyms, or antonyms can also be considered semantically related pairs. In addition, as Moss et al. pointed out, pairs that are functionally related (e.g., broom-FLOOR) could also be considered as semantically related – e.g., the definition of broom involves the concept 'floor'.

In the following section, for brevity's sake, we will focus exclusively on associative/semantic priming studies that have used two experimental paradigms which are posited to tap only automatic processes: the masked priming technique and the single-presentation technique. We believe that focusing on just two techniques avoids the interpretive difficulties inherent in comparing results across very different procedures.

Automatic associative/semantic priming effects

The masked priming technique (Forster, 1998; Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987) has been a fruitful paradigm to study automatic processes at the earliest stages of word recognition. In this technique, the priming stimulus is presented briefly (about 50–66 ms) just prior to the target. A forward pattern mask precedes the prime and, under these conditions, the trace of the prime is relatively inaccessible to conscious report. Prior research with the masked priming technique has shown reliable associative priming effects in the lexical decision task (de Groot & Nas, 1991; Perea & Gotor, 1997; Perea, Gotor, & Nácher, 1997; Perea & Rosa, 2002; Sereno, 1991) and in the naming task (Lukatela & Turvey, 1994; Perea & Gotor, 1997; Williams, 1996). With respect to the evidence for pure semantic priming effects, Williams (1994) found significant semantic priming effects across languages for pairs of words highly related in meaning (either translation equivalents or not) at a 60-ms stimulus-onset asynchrony (SOA) in the lexical decision task. In addition, Williams (1996) found a significant semantic priming effect for synonyms (morning-DAWN; Experiment 2), for category coordinates that shared high-semantic similarity (rain-SNOW; Experiment 3), and for category coordinates that shared low-semantic similarity (rain-BREEZE; Experiment 4) at a 50-ms SOA in the lexical decision task. More recently, Perea and Gotor (1997) found significant semantic priming effects for highly related word pairs (i.e., synonyms or near synonyms) which were not associated at a 66-ms SOA in lexical decision and naming tasks. However, the evidence is not entirely conclusive. At a 66-ms SOA, Perea et al. (1997) failed to find a significant priming effect when category coordinates without associative relation were used as semantically related pairs (arm-NOSE; 6 ms), whereas they found a significant priming effect for associative pairs which were not categorically related (cradle-BABY; 16 ms) and for pairs which were both associatively and categorically related (doctor-NURSE; 18 ms). We should note that Lund, Burgess, and Audet (1998) found a significant 37-ms semantic-only priming effect at a 300-ms SOA (with unmasked primes), which suggests that associative information could have a faster rise time than semantic-only information. (The materials in the Perea et al. study and in the Lund et al. study had been taken from the items used by Chiarello et al., 1990.)

The single-presentation lexical decision task – in which participants have to respond to each presented item (prime or target) – has also been posited as a task that only taps automatic processes (de Mornay Davies, 1998; McNamara & Altarriba, 1988; Shelton & Martin, 1992; but see Moss et al., 1995). The basic rationale behind this technique is that, since there is no obvious pairing between primes and targets (i.e., the stimuli are not presented in pairs, as in the standard priming procedure), participants are less likely to notice relationships among adjacent words and, as a consequence, strategic effects are supposed to be reduced. For instance, backward priming effects do not seem to occur with the single-presentation technique (e.g., see de Mornay Davis, 1998; Shelton & Martin, 1992). With this paradigm, Shelton and Martin (1992) found a robust effect for associatively related pairs, but they failed to find a semantic priming effect (using unassociated words that had some common features or properties, e.g., bread-CAKE). Similarly, Kotz and Holcomb (1996) found associative but not semantic priming effects in their latency data, although they found similar effects of associative and semantic priming using event-related potentials (as measured by the N400 component). In addition, Moss et al. (1995) found semantic priming effects for category coordinates when primes were presented auditorily, but not when primes and targets were presented visually (except for pairs functionally related such as broom-FLOOR or oven-POTATO), whereas they observed consistent priming effects for associatively related pairs. Finally, McRae and Boisvert (1998) used highly similar prime-target pairs – higher in similarity than the Shelton and Martin items – and obtained significant semantic priming effects with non-associated pairs in both a lexical decision task and a semantic decision task. As a result, McRae and Boisvert (1998) indicated that the pairs used by Shelton and Martin (1992) did not possess sufficient featural overlap to produce priming.

Description of the experiments

The main aim of this study was to examine under which conditions automatic semantic priming effects can be obtained, and to analyze the time course and lifetime of associative/semantic activation in memory. We must keep in mind that the presence of automatic semantic priming effects is a fundamental assumption of distributed models of semantic memory (e.g., Masson, 1995; McRae & Boisvert, 1998; Plaut, 1995). The present series of experiments used two experimental techniques that are supposed to reflect automatic effects: the masked priming technique and the single-presentation technique. To our knowledge, no previous published study has compared associative/semantic priming effects with the same materials using these two paradigms. (In a recent report, McRae and Boisvert (1998) found stronger semantic priming effects with a single-presentation paradigm – with a 200-ms response-stimulus interval (RSI) – than with a standard priming procedure at a 250-ms SOA, but they did not examine the cause of this difference.) Undoubtedly, even though the two techniques are thought to reflect automatic processes, they may involve different underlying processes. On the one hand, the main issue in the masked priming technique is whether the associative/semantic information from the prime can be coded quickly enough to speed recognition of the subsequent target word (see Rayner, Sereno, Lesch, & Pollatsek, 1995): i.e., the time course of semantic priming. On the other hand, the main issue in the single-presentation technique is for how long the associative/semantic information from the identified prime (on trial n-1) is maintained after the participant's response as to affect the identification of the subsequent word: i.e., the lifetime of semantic priming[1]. As McRae and Boisvert (1998) suggested, it is possible that the fact that participants have to respond to every presented item in the single-presentation paradigm may provoke a higher degree of activation of the prime than in the masked priming paradigm, and thereby the size of the semantic priming effect could be greater in the single-presentation technique (at least when the RSI is brief) than in the masked priming technique. We hope that examining how associative/semantic priming effects vary across these paradigms that allegedly tap automatic priming will help us to better understand the processes involved in the word identification system.

Experiment 1 examined the presence of priming effects with semantically related pairs (synonyms, antonyms, and category-coordinates) that were normatively associated at several very short SOAs (ranging from 66 to 166 ms) in the lexical decision task with the masked priming technique[2]. The motivation behind this parametric manipulation of the SOA was that Warren (1977; see also Seidenberg, Waters, Sanders, & Langer, 1984) suggested that the time course of associative/semantic priming might differ depending on the type of semantic relation between the prime and the target. If words are represented as a set of features, word pairs with a high degree of overlap in their feature sets (i.e., synonyms or near synonyms, e.g., labor-WORK) should produce greater priming effects than category coordinates (e.g., rabbit-SQUIRREL: see Lupker, 1984; McRae & Boisvert, 1998; Perea & Gotor, 1997; Plaut, 1995; Seidenberg et al., 1984; Tanenhaus & Lucas, 1987; Williams, 1994). Further, if the time course of activation is directly related to the number of shared features, synonyms and antonyms – but not category co-ordinates – should produce very similar functions. (It could be argued that antonym word pairs – e.g., war-PEACE – also share many features and might be represented by identical feature lists except for the presence of a negative feature on one set, see Warren, 1977.) However, the evidence of a different pattern of activation for the different types of semantic relationships is not clear. Warren (1977) found – in a post-hoc analysis with very few items – that synonyms produced significant facilitation at the 75-ms SOA but not at the 150-ms SOA, whereas antonyms produced the opposite trend. More recently, Hodgson (1991) failed to find a different pattern of activation for six different types of semantic relationships (synonyms, antonyms, coordinates pairs, phrasal associates, conceptual associates, and superordinate-subordinate pairs) across four SOA conditions (83, 150, 250, and 500 ms) in lexical decision and naming. Nonetheless, there were a number of methodological problems in the Hodgson study: (1) The proportion of associatively related pairs varied across the type of relation, and (2) participants did the experiment at each level of SOA and knew about the prime-target relations, which could have induced some strategic processes.

[1] As an anonymous reviewer suggested, the lifetime of semantic priming effects could also be examined with a standard priming technique with a constant prime exposure duration and a manipulation of the SOA. However, SOAs longer than 200–250 ms may induce some strategic (nonautomatic) processes when the primes are identified.

[2] As an anonymous reviewer pointed out, another possibility would be to use the naming task in addition to (or instead of) the lexical decision task. We decided to focus on the lexical decision task because the magnitude of the priming effects tends to be larger, thereby maximizing the chances of obtaining a reliable interaction between the manipulated factors.

We must stress that the manipulation of the SOA in Experiment 1 does not imply the presence of invisible primes (especially at SOAs longer than 70 ms). The main aim in Experiment 1 was to track the time-course of associative/semantic information at very short SOAs (i.e., how the associative/semantic information from the prime can be used to speed recognition of the subsequent word) rather than the influence of the visibility of the prime. In any event, we should note that the presence of morphological effects at SOAs of about 50 ms (in which the masked primes are hardly visible) seems well established, which implies that the masked prime must be processed at a relatively high level (e.g., see Deutsch, Frost, & Forster, 1998; Frost, Forster, & Deutsch, 1997; Grainger, Colé, & Seguí, 1991; see also Lee, Rayner, & Pollatsek, 1999, for evidence of semantic priming effects with the "fast priming" paradigm).

Experiment 2 was identical to Experiment 1, except that the pairs were not normatively associated. In this way, it was possible to examine the time course of activation of purely semantic activation. Experiments 3 and 4 examined the lifetime of associative/semantic priming effects with the single-presentation technique. To examine how associative/semantic activation from the related primes decays over time, Experiment 3 used a long RSI (1,750 ms), whereas Experiment 4 used a shorter RSI (200 ms).

Experiment 1

Method

Participants

A total of 160 students from introductory psychology courses at the University of València took part in the experiment in exchange for course credit. All of them either had normal vision or vision that was corrected-to-normal and were native speakers of Spanish.

Materials

Three sets of 22 related pairs were created using the free-production association norms in Spanish (Algarabel, Sanmartín, García, & Espert, 1986): 22 synonym pairs (e.g., *país-NACIÓN*; the Spanish for country-NATION), 22 antonym pairs (*guerra-PAZ*: war-PEACE), and 22 pairs composed of items from the same semantic category (i.e., category coordinates; e.g., *mesa-SILLA*: table-CHAIR). (Although the primes were always nouns, some of them could also be used as adjectives, e.g., *joven-VIEJO* is the Spanish for youth-OLD MAN as well as for young-OLD.) The characteristics of the word-word pairs are presented in Table 1. The word-word pairs are presented in Table 6. The related primes were matched to the unrelated primes for frequency of occurrence and word length (e.g., *país-NACIÓN* vs. *allá-NACIÓN; país* and *allá* have a frequency of occurrence of 234 and 239 per million words in the Spanish count; Alameda & Cuetos, 1995). Sixty-six word-nonword pairs were also created for the purposes of the lexical decision task. Nonwords were orthographically legal and had been constructed by replacing a letter of a Spanish word other than one of the experimental set. Word-word pairs were counterbalanced across two experimental lists. Participants were randomly assigned to one of the two stimulus lists. The relatedness proportion in the experiment (i.e., the proportion of related words for all word-prime/word-targets pairs, see Neely, 1991) was 0.50, and the non-word ratio (i.e., the proportion of unrelated targets that were nonwords, see Neely, 1991) was 0.75.

To analyze the potential impact of the "degree of semantic relation", we also collected ratings of "semantic relatedness" for every word-word pair (i.e., semantic similarity ratings). A nine-point scale accompanied each word pair in the questionnaire from "not semantically related" (1) to "highly semantically related" (9). Participants were instructed to rate the degree of similarity in meaning of each pair of words. Rating data from a total of 18 additional participants were obtained (see Table 1) for the 132 word-word pairs used in Experiments 1 and 2. We created two stimulus lists similar to those used in the experiments, so participants were presented both related word-word trials and unrelated word-word trials. Not surprisingly, in Experiment 1, synonyms (7.5) and antonyms (7.7) showed higher levels of "semantic relatedness" than category-coordinates (6.8), $t2(42)=2.81$, $P<0.01$, and $t2(42)=3.71$, $P<0.01$, respectively. There were no significant differences between synonyms and antonyms, $t2<1$.

Design

SOA (66, 83, 100, 116, and 166 ms) was varied between participants (32 participants were randomly assigned at each level of SOA), whereas prime-target relatedness (related, unrelated) and type of semantic relationship (synonym, antonym, category coordinate) were varied within participants. Each participant was given a total of 132 experimental trials: 66 word-word trials and 66 word-nonword trials.

Procedure

Participants were tested in groups of 20 to 24 in a quiet room. Presentation of the stimuli and recording of reaction times were controlled by Apple Macintosh Classic II microcomputers. The routines for controlling stimulus presentation and reaction time

Table 1. Characteristics of the word-word pairs in Experiments 1 and 2 [*AS* mean associative strength of each set of pairs (percentage of occurrence of the target in response to the prime in a free association task; range in parentheses), *SSR* semantic similarity rating for each set of pairs, *FqT* median frequency of the targets (/10^6 words, see Alameda & Cuetos, 1995), *LT* mean length of the targets, *FqP* median frequency of the primes, *LP* mean length of the primes]

	AS	SSR	FqT	LT	FqP	LP
Associative + semantic						
Synonyms	0.28 (0.13–0.46)	7.5 (7.1–8.6)	92 (10–650)	5.6 (4–10)	43 (12–887)	4.7 (4–10)
Antonyms	0.27 (0.09–0.55)	7.7 (6.4–8.9)	96 (1–889)	5.5 (3–10)	116 (16–1146)	5.0 (4–6)
Coordinates	0.25 (0.12–0.50)	6.8 (4.9–8.3)	73 (2–514)	4.8 (3–7)	74 (8–550)	4.9 (4–7)
Semantic only						
Synonyms	–	6.7 (5.0–8.1)	16 (1–36)	6.6 (5–8)	97 (11–887)	5.0 (4–6)
Antonyms	–	6.7 (5.3–8.4)	29 (1–299)	6.5 (4–10)	88 (9–432)	5.0 (4–7)
Coordinates	–	5.8 (4.7–7.2)	29.5 (3–1,229)	5.6 (4–8)	67 (6–410)	5.1 (4–7)

collection were obtained from Lane and Ashby (1987) and from Westall, Perkey, and Chute (1986), respectively. Reaction times were measured from target onset until participants' response. On each trial, a forward mask composed of a row of six hash-marks (######) was presented for 500 ms on the center of the screen. Next, a centered lowercase prime word was presented for 66, 83, 100, 116, or 166 ms (depending on the SOA condition). Primes were immediately replaced by an uppercase target item (i.e., SOA is confounded with prime exposure in this experiment). Participants were instructed to press one of two buttons on the keyboard ("ç" for yes and "z" for no) to indicate whether the uppercase letter string was a legitimate Spanish word or not. This decision had to be done as quickly and as accurately as possible. When the participant responded, the target disappeared from the screen. The inter-trial interval was 1,500 ms. Participants were not informed of the presence of lowercase words (except at the 166-ms SOA, in which the prime was clearly visible). Each participant received a total of 20 practice trials (with the same manipulation as in the experimental trials) prior to the 132 experimental trials. Stimulus presentation was randomized, with a different order for each participant. The session lasted approximately 13 min.

Results and discussion

Incorrect responses (2.9%) and reaction times less than 300 ms or greater than 1,300 ms (2.8% of the data) were excluded from the latency analysis. Mean lexical latencies for correct responses and mean error rates were calculated across individuals and across items. Participant and item analyses of variance (ANOVAs) based on the participants' and items' response latencies and error rates were conducted based on a 5 (SOA: 66, 83, 100, 116, and 166 ms) × 2 (Semantic relatedness: related, unrelated) × 3 (Type of semantic relationship: synonyms, antonyms, and coordinates) × 2 (List: list 1, list 2) design. In this and subsequent analyses, the factor list was included as a dummy variable to extract the variance due to the error associated with the lists (see Pollatsek & Well, 1995) and the significance level was set to $P < 0.05$. The mean lexical decision latencies and error rates from the participant analysis are presented in Table 2.

Table 2. Mean lexical decision times (in ms) and percentage of errors (in parentheses) on target words in Experiment 1 (associative + semantic pairs) (*Priming effect* difference between the unrelated word condition and the related word condition, *SOA* stimulus-onset asynchrony)

Prime-target relatedness	Related	Unrelated	Priming effect
SOA = 66 ms			
Synonyms	746 (2.4)	754 (2.8)	8 (0.4)
Antonyms	750 (3.6)	762 (6.4)	12 (2.8)
Coordinates	722 (2.8)	743 (3.7)	21 (0.9)
SOA = 83 ms			
Synonyms	713 (2.1)	727 (1.3)	13 (–0.8)
Antonyms	731 (1.9)	746 (3.7)	15 (1.8)
Coordinates	711 (1.3)	729 (2.8)	18 (1.5)
SOA = 100 ms			
Synonyms	676 (2.2)	696 (1.8)	20 (–0.4)
Antonyms	685 (3.4)	730 (4.8)	45 (1.4)
Coordinates	668 (1.9)	689 (1.6)	21 (–0.3)
SOA = 116 ms			
Synonyms	707 (2.5)	722 (3.4)	15 (0.9)
Antonyms	708 (2.8)	742 (4.6)	34 (1.8)
Coordinates	684 (1.5)	717 (2.1)	33 (0.6)
SOA = 166 ms			
Synonyms	709 (3.4)	738 (3.1)	29 (–0.3)
Antonyms	706 (1.6)	747 (4.9)	41 (3.3)
Coordinates	689 (0.9)	721 (5.8)	32 (4.9)

The ANOVA on the latency data showed a significant effect of semantic relatedness, $F1(1, 150) = 82.34$, MSE = 1,639; $F2(1, 60) = 44.55$, MSE = 2,435: targets preceded by related primes were responded to more rapidly than targets preceded by unrelated primes. The SOA × Relatedness interaction approached statistical significance in the analysis by participants, $F1(4, 150) = 2.18$, MSE = 1,639, $P = 0.07$; $F2(4, 240) = 1.82$, MSE = 1,134, $P > 0.10$, which reflected a tendency towards an incremental effect of priming. In any case, the effect of relatedness was significant at all SOAs (14, 15, 28, 27, and 34 ms at the 66, 83, 100, and 166-ms SOAs, respectively), all $F1$s > 4.86, all $F2(1, 60) > 7.20$. The Relatedness × Type of relation interaction did not approach significance (both Ps > 0.10): the priming effects were 17, 30, and 35 ms for the synonyms, antonyms, and category coordinates, respectively. The SOA × Relatedness × Type of semantic relationship interaction did not approach significance either (both Ps > 0.10). The effect of Type of semantic relationship was significant in the analysisbyparticipants, $F1(2, 300) = 25.05$, MSE = 1,781; $F2(2, 60) = 1.44$, MSE = 26,456, $P > 0.10$ (the mean response times were 719, 731, and 707 ms for the synonyms, antonyms, and category coordinates, respectively). We suspect that it was due to the different frequency of usage of some of the targets in the different conditions.

The ANOVA on the error data revealed a main effect of relatedness, $F1(1, 150) = 14.56$, MSE = 24.83; $F2(1, 60) = 6.26$, MSE = 35.2, in which targets preceded by related primes were responded to more accurately than those preceded by unrelated primes (2.3% vs 3.5%, respectively). The main effect of type of relation was significant in the analysis by participants, $F1(2, 300) = 7.64$, MSE = 23.83; $F2(2, 60) < 1$, MSE = 130.0 (the error rates were 2.5%, 3.8%, and 2.4% for the synonyms, antonyms, and category coordinates, respectively). In addition, the Relatedness × Type of semantic relationship interaction was significant in the analysis by participants, $F1(2, 300) = 4.52$, MSE = 24.12; $F2(2, 60) = 1.91$, MSE = 35.2 : significant effects of relatedness were found for antonyms (a 2.1% priming effect), $F1(1, 150) = 12.17$, MSE = 32.56; $F2(1, 60) = 6.91$, MSE = 35.2, and for coordinates (in the analysis by participants, a 1.5% priming effect), $F1(1, 150) = 11.28$, MSE = 16.2, $F2(1, 60) = 3.16$, MSE = 35.2, $P < 0.082$, but not for synonyms (a virtually null priming effect), both Fs < 1. Neither the SOA × Relatedness interaction nor the SOA × Relatedness × Type of semantic relationship interaction approached significance.

To assess the influence of associative strength on the size of priming (in the latency analysis), we conducted a series of simple regression analyses between these variables at each level of SOA. Only at the 66-ms SOA did we find a significant relationship between associative strength and magnitude of priming, $r = 0.34$, $F(1, 64) = 8.44$. The r values with the other SOAs were far from statistical significance (0.13, 0.16, 0.11, and –0.03 at the 83, 100, 116, and 166-ms SOA, respectively)[3]. (We must indicate that no reliable effects of semantic similarity were obtained at any SOA.)

In sum, it seems that the priming effects that occurred at the shortest SOA (66-ms SOA) were, at least in part, due to a set of highly associated pairs. In contrast, it could be argued that the priming effects at SOAs of 83 ms (and longer) were mostly caused by the existence of a semantic relation between prime and target. These results suggest that one would expect "semantic-only" priming starting at SOAs of about 80–100 ms. This possibility was tested in Experiment 2, which was identical to Experiment 1 except that the prime-target pairs were not associated according to free-production associative norms. It could be argued that one cannot be sure that there are no associative relationships between semantically related words that do not occur in association norms (see Balota & Paul, 1996). However, it is obvious that there must be a clear difference in associative strength between pairs that appear in published association norms relative to those pairs that do not appear in these norms.

Experiment 2

Method

Participants

One hundred and sixty participants from introductory psychology courses at the University of València participated in this experiment in exchange for course credit. None of them had taken part in Experiment 1.

Materials

Three sets of 22 semantically related pairs were created: 22 synonym pairs (e.g., *barco-BUQUE*: boat-VESSEL), 22 antonym pairs (e.g., *orden-CAOS*: order-CHAOS) and 22 category coordinates (e.g., gato-CONEJO: cat-RABBIT) (Table 7). Unlike Experiment 1, word pairs were not associatively related in the Spanish association norms (Algarabel et al., 1986). As a result, associative strength would not likely be responsible for any relatedness effects in this experiment (i.e., the selected prime-target pairs would be weakly associated at most). We also used 66 word-nonword pairs, similarly to Experiment 1. The characteristics of the word-word pairs are presented in Table 1. As in Experiment 1, synonyms (6.7) and antonyms (6.7) showed higher levels of semantic relatedness than category-coordinates (5.8), $t2(42) = 3.04$, $P < 0.01$ and $t2(42) = 3.89$, $P < 0.01$, respectively. There were no significant differences between synonyms and antonyms, $t2 < 1$. We should note that the rating of semantic relatedness was higher for the word pairs that were semantically and associative related (Experiment 1) than for the word pairs that were semantically related only (Experiment 2: 7.3 vs 6.4, respectively), $F2(1, 126) = 43.54$, $P < 0.01$. Interestingly, the effect of Type of semantic relationship was remarkably similar in the two experiments (see Table 1). Although it is possible that the pairs in Experiment 1 were "more semantically similar" than the pairs in Experiment 2, we must keep in mind that these ratings might have also been influenced by associative factors. (This would not be surprising. For instance, rated subjective familiarity show higher values for imageable rather than for non-imageable nouns matched on frequency of occurrence.)

Design and procedure

The design and procedure were the same as in Experiment 1.

Results and discussion

Incorrect responses (5.5%) and reaction times less than 300 ms or greater than 1,300 ms (4.5% of the data) were excluded from the latency analysis. As in Experiment 1, participant and item ANOVAs based on the participants' and items' response latencies and error rates were conducted based on a 5 (SOA: 66, 83, 100, 116, and 166 ms) × 2 (Semantic relatedness: related, unrelated) × 3 (Type of semantic relationship: synonyms, antonyms, and coordinates) × 2 (List: list 1, list 2) design. The mean lexical decision time and the error rate on the stimulus words are shown in Table 3.

The ANOVA on the latency data revealed a main effect of relatedness, $F1(1, 150) = 47.53$, MSE = 2,166; $F2(1, 60) = 41.83$, MSE = 655: targets preceded by related primes were responded to more rapidly than targets preceded by unrelated primes. The SOA × Related-

Table 3. Mean lexical decision times (in ms) and percentage of errors (in parentheses) on target words in Experiment 2 (Semantic-only pairs)

Prime-target relatedness	Related	Unrelated	Priming effect
SOA = 66 ms			
Synonyms	791 (10.0)	788 (11.9)	–3 (1.9)
Antonyms	768 (3.4)	765 (7.0)	–3 (3.6)
Coordinates	733 (5.7)	742 (5.1)	9 (–0.6)
SOA = 83 ms			
Synonyms	799 (9.6)	831 (10.6)	32 (1.0)
Antonyms	799 (5.2)	817 (5.2)	18 (0.0)
Coordinates	735 (1.2)	768 (5.1)	33 (3.9)
SOA = 100 ms			
Synonyms	772 (7.0)	801 (9.0)	29 (2.0)
Antonyms	756 (2.2)	771 (5.0)	15 (2.8)
Coordinates	723 (1.2)	740 (3.1)	17 (1.9)
SOA = 116 ms			
Synonyms	792 (8.1)	813 (9.1)	21 (1.0)
Antonyms	779 (4.8)	803 (3.4)	24 (–1.4)
Coordinates	733 (1.6)	764 (3.4)	31 (1.8)
SOA = 166 ms			
Synonyms	795 (6.1)	820 (10.2)	25 (4.1)
Antonyms	795 (3.1)	817 (1.8)	22 (–1.3)
Coordinates	748 (0.9)	790 (4.0)	42 (3.1)

[3]We should note that the (significant) r value of the 66-ms SOA was not significantly different from the r value at the 83-ms SOA, although it was significantly different from the r value at the 100-ms SOA, $t(63) = 2.07$, $P < 0.05$. In any event, the P value corresponding to the r value at the 83-ms SOA was far from statistical significance ($P > 0.15$), whereas the P value corresponding to the Pearson coefficient at the 66-ms SOA was less than 0.01.

ness interaction was also significant, $F1(4, 150) = 2.98$, MSE = 2,166; $F2(4, 240) = 2.50$, MSE = 1,607: significant effects of relatedness were found at all levels of SOA except at the 66-ms SOA: 66 ms (1 ms), both $F\text{s} < 1$; all other SOAs had $F1\text{s} > 8.52$ and $F2\text{s} > 9.97$ (the priming effects were 27, 21, 26, and 30 ms at the 83, 100, 116, and 166-ms SOA, respectively). As in Experiment 1, the Relatedness × Type of semantic relationship interaction did not approach significance (both $P\text{s} > 0.10$): the priming effects were 21, 14, and 27 ms for synonyms, antonyms, and category coordinates, respectively. The SOA × Relatedness × Type of relation interaction did not approach significance either (both $P\text{s} > 0.10$). Finally, the main effect of Type of semantic relationship was significant, $F1(2, 300) = 108.15$, MSE = 2,222; $F2(2, 60) = 5.42$, MSE = 44,152, again possibly because of the different frequency of usage of the items (and/or the number of letters of the target words) across conditions (the mean response times were 800, 787, and 748 ms for the synonyms, antonyms, and category coordinates, respectively): post-hoc tests with the Tukey procedure ($P < 0.05$ by participants and items) showed a reliable difference between the response time on synonyms and category coordinates.

The ANOVA on the error data showed a main effect of relatedness (4.7% vs 6.3% for the related and the unrelated condition, respectively), $F1(1, 150) = 13.33$, MSE = 44.53; $F2(1, 60) = 9.17$, MSE = 40.28. The effect of type of relation was significant in the analysis by participants, $F1(2, 300) = 76.56$, MSE = 43.58; $F2(2, 60) = 2.65$, MSE = 784.9, $P < 0.08$ (the error rates were 9.2%, 4.1%, and 3.1% for the synonyms, antonyms, and category coordinates, respectively). The other effects were not significant.

To summarize, in the latency analysis, the effects of semantic-only priming were significant at SOAs of 83 ms and longer, but not at the 66-ms SOA (a 1-ms effect in the analysis by participants and a nonsignificant 6-ms effect in the analysis by items). Similarly to Experiment 1, all three types of semantic relations (synonyms, antonyms, and category-coordinates) showed similar priming effects and a similar time course of priming effects.

To analyze the influence of the role of normative association on the magnitude of the semantic priming effects, we conducted a combined analysis of latency data for words from Experiments 1 and 2. Not surprisingly, this joint analysis showed that the main effect of relatedness was significant, $F1(1, 300) = 124.5$, MSE = 1,902.3; $F2(1, 120) = 86.38$, MSE = 2,387. In addition, semantic relatedness interacted with the SOA (essentially because of the small priming effects at the 66-ms SOA), $F1(4, 300) = 4.24$, MSE = 1,902.3; $F2(4, 480) = 3.12$, MSE = 1, 371. More important, semantic relatedness did not interact with the other factors (all $P\text{s} > 0.15$): in other words, there were no signs of a different time course of associative/semantic priming effects for the various types of semantic relationships. In this light, the magnitude of the semantic priming effect was similar with associative + semantic pairs and with purely semantic pairs (24 and 21 ms in Experiments 1 and 2, respectively), as deduced by the lack of interaction between normative association and semantic relatedness, $F1(1, 300) < 1$; $F2(1, 120) = 1.80$, MSE = 1,581.5, $P > 0.15$. Recently, Moss et al. (1995) found that the presence of normative association resulted in a significant increase in the magnitude of the priming effect (relative to the semantic-only priming effect): this is the so-called 'associative boost' (see Lucas, 2000; but see Fischler, 1977; Hino, Lupker, & Sears, 1997; Ostrin & Tyler, 1993; Perea & Gotor, 1997; Seidenberg et al., 1984, for failures to obtain this associative boost). Nonetheless, we should note that there were differences in word frequency across the two experiments. Associative targets were more frequent than semantic-only targets: not surprisingly, it is more likely to give a high-frequency word than a low-frequency word in response to the prime in a free association task. Since there are reports of stronger semantic priming effects for lower-frequency targets (e.g., see Becker, 1979; Chiarello et al., 1990; Stanovich & West, 1983), it is therefore possible that some of the differences between the present study and the Moss et al. study could be due to the fact that targets in Experiment 2 were less frequent than targets in Experiment 1.

The fact that the patterns of priming for the three different prime-target relationships (synonyms, antonyms, and category coordinates) were similar across the different SOAs poses some problems for a spreading account (see Hodgson, 1991, for a similar pattern of results; see also Williams, 1996). Overall, the priming effects in Experiments 1 and 2 were 19 ms for synonyms, 22 ms for antonyms, and 31 ms for category coordinates. That is, the semantic priming effect seems to be, if anything, a bit higher for the items judged as less semantically related (category coordinates). Interestingly, a recent meta-analytic study on semantic priming (Lucas, 2000) has also shown a similar effect size for synonyms, antonyms, and category coordinates in previous research (0.21, 0.20, and 0.23, respectively). As we indicated earlier, synonyms should benefit more from spreading activation in semantic memory, since synonyms (and probably antonyms) share more semantic features (i.e., they are more "similar" in meaning) than category coordinates. However, that was not the case (see also Williams, 1996). Undoubtedly, it does not seem very efficient for the memory system to spread the activation from the prime word towards a vast and diffuse network of concepts (see Fischler, 1977; Hodgson, 1991; McKoon & Ratcliff, 1992, for similar arguments).

Recently, a number of connectionist networks have also been proposed (e.g., Cree, McRae, & McNorgan, 1999; Masson, 1995; Moss, Hare, Day, & Tyler, 1994; Plaut, 1995; Sharkey & Sharkey, 1992), in which each concept is represented not by a particular unit, as in the classic spreading-activation theories, but by a particular pattern of activity over a large number of processing units. That is, activation does not spread between concepts but between features. One of the basic assumptions of these models, namely, the presence of automatic semantic priming effects, is clearly supported by the present data. However, semantic priming effects in these models are predicted to be stronger for highly similar pairs (because of semantic overlap) than for loosely related pairs (e.g., see Cree et al., 1999; Plaut, 1995). Since our results showed similar priming effects for synonyms and category coordinates, they also seem to pose a problem for these models. (Of course, it might be argued that the semantic activation from the prime could reach some asymptotic level, which would minimize any differences in semantic similarity, but this is not an appealing proposal.)

Experiment 3

In Experiments 1 and 2, we found a reliable semantic priming effect at several short SOAs, which suggests that semantic priming effects are automatic. The goal of Experiments 3 and 4 was to examine the presence of semantic priming effects with another technique that also taps automatic processes: the single-presentation technique. Participants had to make a lexical decision to both the prime (trial n-1) and the target (trial n). Given that there were no reliable effects of the type of semantic relationship in Experiments 1 and 2, only normative association (associated, non-associated pairs) and semantic relatedness (related, unrelated) were manipulated in this experiment. (We must keep in mind that, unlike the masked priming technique, the single-presentation technique does not provide information on the time course of activation of the different semantic relationships.) Specifically, the items in Experiments 3 and 4 consisted of associatively and semantically related pairs as well as of pairs that were only semantically related (i.e., all these pairs were a subset of the pairs used in Experiment 1 and 2). To examine the lifetime of associative/semantic activation, the RSI was set to 200 ms and 1,750 ms in Experiments 3 and 4, respectively. Thus, the SOA in Experiment 3 was the decision latency to the prime plus 200 ms (as in McRae & Boisvert, 1998; and Shelton & Martin, 1992, Experiment 4), whereas the SOA in Experiment 4 was the decision latency to the prime plus 1,750 ms.

Method

Participants

A total of 21 students from introductory psychology courses at the University of València took part in the experiment in exchange for course credit. None of them had participated in the previous experiments.

Materials

Sixty related word-word pairs were randomly selected from the pairs in Experiments 1 and 2: 30 were both semantically related and normatively associated and 30 were semantically, but not associatively, related. The characteristics of the word-word pairs are presented in Table 4. (The word-word pairs are presented in Table 8.) The 30 targets from the semantically related pairs and the 30 targets from the associated pairs were divided into three groups of 10 targets each. Three stimulus lists were created by matching each of those targets with either its semantically related (or associative prime), an unrelated word prime, or a nonword prime in a Latin square design. Each stimulus list contained 10 semantically related prime-target pairs, 10 associated prime-target pairs, 20 unrelated word-word pairs, and 20 nonword prime-word target pairs. For the 60 nonword targets, there were 30 word primes and 30 nonword primes. Participants were randomly assigned to one of the three stimulus lists.

Design

Semantic relatedness (related, unrelated) and normative association (associated, non-associated) were varied within participants.

Procedure

Participants were tested in groups of five to ten in a quiet room. On each trial, a lowercase letter string was presented on the center of the screen. (In this experiment, there was no fixation point, to keep the RSI as low as possible.) Participants were instructed to press one of two buttons on the keyboard ("ç" for yes and "z" for no) to indicate whether the letter string was a legitimate Spanish word or not. This decision had to be done as quickly and as accurately as possible. When the participant responded, the stimulus item disappeared from the screen. After an inter-trial interval of 200 ms, the next letter string was presented. Each participant received a total of 24 practice trials prior to the experimental trials. Presentation of the pairs was randomized within each group, and each participant received a different random order. The session lasted approximately 13 min.

Results and discussion

Incorrect responses (4.5%) and reaction times less than 300 ms or greater than 1,300 ms (1.6% of the data) were excluded from the latency analysis. Participant and item ANOVAs based on the participants' and items' mean response latencies and error rates were conducted based on a 2 (Semantic relatedness: related, unrelated) × 2 (Normative association: associative, semantic) × 3 (List: list 1, list 2, list 3) design. The mean lexical decision time and the error rate on the stimulus words are given in Table 5.

The main effect of relatedness was statistically significant, $F1(1, 18) = 6.35$, $MSE = 1{,}533$; $F2(1, 54) = 4.74$, $MSE = 3{,}026$: related word targets were responded to 21 ms faster than unrelated word targets. The main

Table 4. Characteristics of the word-word pairs in Experiments 3 and 4 (for abbreviations see Table 1)

	AS	SSR	FqT	LT	FqP	LP
Associative + semantic	0.32 (0.15–0.55)	7.5 (7.1–8.6)	94 (2–899)	5.3 (3–10)	51 (2–604)	4.9 (4–7)
Semantic only	–	5.8 (4.7–7.2)	20 (1–141)	6.7 (4–8)	83 (11–887)	5.2 (4–6)

Table 5. Mean lexical decision times (in ms) and percentage of errors (in parentheses) on target words in Experiments 3 and 4 (*RSI* response-stimulus interval) (*Priming effect* difference between the unrelated word-word condition and the related word-word condition)

Prime-target relatedness	Related	Unrelated	Priming effect
Experiment 3 (RSI = 200 ms)			
Type of relation			
Associative + semantic	617 (1.4)	639 (1.9)	21 (0.5)
Semantic only	667 (5.7)	688 (9.0)	21 (3.3)
Experiment 4 (RSI = 1,750 ms)			
Type of relation			
Associative + semantic	589 (1.3)	612 (1.0)	23 (−0.3)
Semantic only	672 (8.2)	679 (7.9)	7 (−0.3)

effect of normative association was also significant, $F1(1, 18) = 31.25$, MSE = 1,654; $F2(1, 54) = 8.67$, MSE = 11,589. More important, there were no signs of an interaction between the two factors, both $F\text{s} < 1$ (both the associative and the semantic pairs showed a 21-ms priming effect). Not surprisingly, the Pearson coefficient between associative strength and magnitude of priming (for associative pairs) was quite small, $r = 0.07$. The analysis of error data only showed that participants made more errors for the semantic pairs than for the associative pairs, $F1(1, 18) = 11.08$, MSE = 61.9; $F2(1, 54) = 4.79$, MSE = 204.5, which is probably due to the lower frequency of usage of some of the targets in the semantic-only condition.

The results show a significant effect of semantic relatedness (21 ms), which was similar for associative + semantic and semantic-only pairs. In other words, semantic-only priming effects can be found with the single-presentation technique, at least when the RSI is very short (200 ms), replicating McRae and Boisvert (1998). However, unlike McRae and Boisvert, who found stronger semantic priming effect in the single-presentation technique (at a brief RSI, 200 ms) than in a standard priming technique at a 250-ms SOA (47 vs 29 ms, respectively), the present experiments failed to provide any clear signs of a different size of the semantic priming effect with the two techniques (21 vs 26 ms, respectively). It may be important to note that, in the McRae and Boisvert study, the stronger priming effects in their single-presentation lexical decision task occurred only for artifacts (43 vs 17 ms, respectively), but not for living things (55 vs 57 ms, respectively); in contrast, in a semantic decision task ("is it a concrete object?"), McRae and Boisvert found that the stronger semantic priming effects in single-presentation paradigm (relative to the standard priming procedure) occurred especially for the living things (107 vs 54 ms, respectively) rather than for the artifacts (47 vs 35 ms, respectively). The reason for these divergences are not obvious.

After establishing a semantic priming effect at a brief RSI, it is important to examine whether or not activation between word pairs that are semantically related – but not associated – might die out more quickly than for word pairs that are associated (see Shelton & Martin, 1992). In this light, it is worth noting that Napps (1989) failed to find a priming effect for synonyms when the interval between stimuli was over 2 s. To test this possibility, in Experiment 4, the RSI was set to 1,750 ms.

Experiment 4

Method

Participants

A total of 39 students from introductory psychology courses at the University of València took part in the experiment in exchange for course credit. None of them had participated in the previous experiments.

Materials and design

The materials and design were the same as in Experiment 3.

Procedure

Participants were tested in groups of 20 to 24 in a quiet room. On each trial, the sequence "> <" was presented for 200 ms on the center of the screen. After a 50-ms blank, a lowercase letter string was presented. Participants were instructed to press one of two buttons on the keyboard ("ç" for yes and "z" for no) to indicate whether the letter string was a legitimate Spanish word or not. This decision had to be done as quickly and as accurately as possible. When the participant responded, the stimulus item disappeared from the screen. The inter-trial interval was 1.5 s. Each participant received a total of 24 practice trials prior to the 240 (120 words and 120 nonwords) experimental trials. Presentation of the pairs was randomized within each group, and each participant received a different random order. The session lasted approximately 18 min.

Results and discussion

Incorrect responses (5.1%) and reaction times less than 300 ms or greater than 1,300 ms (1.5% of the data) were excluded from the latency analysis. Participant and item ANOVAs based on the participants' and items' mean response latencies and error rates were conducted based on a 2 (Semantic relatedness: related, unrelated) × 2 (Normative association: associative, semantic) × 3 (List: list 1, list 2, list 3) design. The mean lexical decision time and the error rate on the stimulus words are given in Table 5.

The main effect of relatedness was statistically significant, $F1(1, 36) = 4.90$, MSE = 1771; $F2(1, 54) = 4.67$, MSE = 996: related word targets were responded to 14 ms faster than unrelated word targets. The main effect of normative association was also significant, $F1(1, 36) = 125.62$, MSE = 1,753; $F2(1, 54) = 20.21$, MSE = 11,581. Although the interaction between the two factors was only marginally significant in the analysis by items, $F2(1, 27) = 2.86$, MSE = 2,423, $P < 0.10$; $F1(1, 36) < 1$, MSE = 996, it is important to note that the 23-ms associative priming effect on the latency data was statistically significant, $F1(1, 36) = 7.43$, MSE = 1,346; $F2(1, 27) = 13.76$, MSE = 537, whereas the 7-ms semantic priming effect was far from significance, both Fs < 1[4]. The Pearson coefficient between associative strength and magnitude of priming (for associative pairs) was relatively small, $r = 0.18$, $P > 0.10$. The analysis of error data only showed that participants made more errors for the semantic pairs than for the associative pairs, $F1(1, 36) = 40.97$, MSE = 45.6; $F2(1, 54) = 9.29$, MSE = 154.7.

The results of the present experiment are straightforward. The priming effect was essentially due to the associatively related pairs (a 23-ms priming effect), whereas the priming effect for the semantic-only pairs was rather small (a nonsignificant 7-ms priming effect). The lack of a reliable semantic priming effect with nonassociated pairs at a long RSI suggests that activation from semantic-only pairs might decay more rapidly than activation for associative pairs. However, there are alternative explanations for this finding. As a reviewer pointed out, one could argue that the lack of a purely semantic priming effect at the long RSI in the single-presentation technique could have been due to the use of expectancy generation, which could have helped associative rather than purely semantic pairs. In any event, the percentage of related pairs in Experiment 3 was quite low (20 related pairs out of 240 trials), which seems to discard the use of expectancy generation as a useful strategy.

General discussion

There is currently a controversy on whether nonassociative, semantic priming effects are automatic (e.g., McRae & Boisvert, 1998; Perea & Gotor, 1997; Shelton & Martin, 1992; Thompson-Schill et al., 1998). The present experiments showed a semantic priming effect with two techniques that tap automatic processes: a standard priming procedure with brief SOAs and the single-presentation technique. Specifically, we replicated and extended the masked semantic priming experiments of Perea and Gotor (1997) by providing data for several short SOAs (ranging from 66 to 166 ms; Experiments 1–2). Interestingly, we found no signs of a moderation of priming by type of semantic relationship (synonyms, antonyms, category coordinates) with this priming procedure, extending the results of Hodgson (1991) and Williams (1996). Finally, we found that these same materials can also produce a semantic priming effect with the single-presentation technique, at least when the RSI is short (200 ms), replicating the semantic priming effects obtained by McRae and Boisvert (1998).

In addition, it is worth noting that the present results showed some evidence that suggests that associative + semantic and semantic-only priming effects might have a different time course and lifetime: (1) priming for pairs that are associatively and semantically related (e.g., dog-CAT) appears to have a faster rise time than for semantic-only pairs (e.g., cat-RABBIT; masked priming technique, Experiments 1 and 2), and (2) priming effects appear to decay more quickly for semantic-only pairs than for pairs that are associatively and semantically related (single-presentation technique; Experiments 3 and 4).

Associative priming effects

Associative priming effects were significant with the masked priming technique (even at the briefest SOA) and the single-presentation technique, which is consistent with previous research (e.g., Moss et al., 1995; Perea & Gotor, 1997; Perea et al., 1997; Sereno, 1991; Shelton & Martin, 1992). Interestingly, the influence of associative strength – as a predictor of the priming effect – was only significant at the briefest SOA (66 ms). In contrast, at SOAs of 83 ms and longer, associative strength does not appear to play a critical role for priming to occur (see also Hodgson, 1991). Likewise, prior research has often failed to find a reliable relationship between the size of priming and the associative strength at relatively long SOAs (e.g., Hines, Czerwinski, Sawyer, & Dwyer, 1986) or when the prime and the target are presented simultaneously in a double lexical decision task (e.g., Fischler, 1977).

Thus, the results at the shortest SOA (66 ms; Experiment 1) can be readily explained in terms of automatic priming that would spread along the paths of associatively related nodes. This interpretation is consistent with the fact that previous research has found similar masked priming effects for associative pairs that were not categorically related and for pairs that were both associatively and categorically related (e.g., baby-CRADLE vs. doctor-NURSE, Perea et al., 1997). Since related pathways in memory have been partially activated, related targets can be processed more rapidly than unrelated targets, independently of the type of semantic relation between the prime and the target. But why do automatic associative priming effects occur? Obviously, sentences do not usually contain strongly associated words. As Forster (1979) pointed out, “the frequency of those pairs scarcely justifies an elaborate scanning of the associates of every word in the sentence in the hope that a pair of associatively related words will be present” (p. 74). Nonetheless, it seems that the terms for things frequently connected in experience become themselves connected in the mental lexicon (see Fodor, 1983; Hino et al., 1997). Thus, this associative priming effect may have little to do with semantics. For instance, it has been suggested that a major determinant of priming effects is the frequency with which the two words of a pair

[4] It is worth noting that the small number of data points per condition (10; 39 subjects overall) was probably the cause of the lack of power to detect the interaction between associative relatedness and normative association. The number of items was higher (60; the number of data points per condition was 13) and this is (probably) why the item analysis was more powerful to detect the interaction.

Table 6. Word-word pairs in Experiment 1: associative + semantic pairs

Synonyms	Antonyms	Category coordinates
cara-ROSTRO (face-FACE)	salud-ENFERMEDAD (health-DISEASE)	mesa-SILLA (table-CHAIR)
seno-PECHO (bosom-BREAST)	joven-VIEJO (young-OLD)	perro-GATO (dog-CAT)
miembro-PARTE (member-PART)	venta-COMPRA (sale-PURCHASE)	rayo-TRUENO (lightning-THUNDER)
carga-PESO (burden-WEIGHT)	vida-MUERTE (life-DEATH)	diente-MUELA (tooth-MOLAR)
dama-SEÑORA (dame-LADY)	odio-AMOR (hate-LOVE)	luna-SOL (moon-SUN)
gusto-SABOR (taste-FLAVOUR)	noche-DíA (night-DAY)	ciento-MIL (hundred-THOUSAND)
hoja-PAPEL (sheet-PAPER)	éxito-FRACASO (success-FAILURE)	nariz-BOCA (nose-MOUTH)
fraile-MONJE (friar-MONK)	negro-BLANCO (black-WHITE)	hambre-SED (hunger-THIRST)
núcleo-CENTRO (nucleus-CENTRE)	calor-FRÍO (heat-COLD)	conde-DUQUE (count-DUKE)
país-NACIÓN (country-NATION)	curva-RECTA (curve-STRAIGHT LINE)	francés-INGLÉS (French-ENGLISH)
deber-OBLIGACIÓN (duty-OBLIGATION)	guerra-PAZ (war-PEACE)	pueblo-CIUDAD (town-CITY)
labor-TRABAJO (labor-WORK)	verdad-MENTIRA (truth-LIE)	plata-ORO (silver-GOLD)
error-FALLO (error-MISTAKE)	causa-EFECTO (cause-EFFECT)	hijo-PADRE (son-FATHER)
azar-SUERTE (hazard-CHANCE)	verso-PROSA (verse-PROSE)	mano-PIE (hand-LEG)
muro-PARED (wall-WALL)	suma-RESTA (sum-SUBTRACT)	balcón-VENTANA (balcony-WINDOW)
norma-REGLA (norm-RULE)	premio-CASTIGO (reward-PUNISHMENT)	rosa-CLAVEL (rose-PINK)
fase-ETAPA (phase-STAGE)	pobre-RICO (poor-RICH)	raíz-TALLO (root-STEM)
casa-HOGAR (house-HOME)	final-PRINCIPIO (end-BEGINNING)	vino-AGUA (wine-WATER)
frase-ORACIÓN (phrase-SENTENCE)	placer-DOLOR (pleasure-PAIN)	duro-PESETA (shilling-PENNY)
honra-HONOR (dignity-HONOUR)	loco-CUERDO (crazy-SANE)	vista-OIDO (sight-HEARING)
cosa-OBJETO (thing-OBJECT)	risa-LLANTO (laugh-CRYING)	hora-MINUTO (hour-MINUTE)
hecho-ACTO (deed-ACT)	sombra-SOL (shade-SUNLIGHT)	julio-AGOSTO (July-AUGUST)

Table 7. Word-word pairs in Experiment 2: semantic-only pairs

Synonyms	Antonyms	Category coordinates
casa-VIVIENDA (house-FLAT)	orden-CAOS (order-CHAOS)	hierro-COBRE (iron-COPPER)
hijo-VÁSTAGO (son-OFFSPRING)	prisa-CALMA (hurry-CALM)	vino-CERVEZA (wine-BEER)
madre-SEÑORA (mother-MADAM)	gasto-AHORRO (expense-SAVING)	junio-MARZO (Juny-MARCH)
campo-TERRENO (field-TERRAIN)	odio-TERNURA (hate-FONDNESS)	moro-INDIO (Moor-INDIAN)
cambio-PERMUTA (exchange-BARTER)	final-COMIENZO (end-INITIATION)	seda-ALGODÓN (silk-COTTON)
falta-PECADO (offense-SIN)	loco-CABAL (crazy-SANE)	falda-CAMISA (skirt-SHIRT)
dolor-MOLESTIA (pain-DISCOMFORT)	risa-LÁGRIMAS (laugh-TEARS)	gato-CONEJO (cat-RABBIT)
jardín-VERGEL (garden-ORCHARD)	lujo-POBREZA (luxury-POVERTY)	nieto-HERMANO (grandson-BROTHER)
barco-BUQUE (boat-VESSEL)	valor-COBARDÍA (courage-COWARDICE)	templo-MUSEO (temple-MUSEUM)
obra-TRABAJO (word-LABOUR)	premio-SANCIÓN (prize-SANCTION)	avión-COCHE (plane-CAR)
pared-TABIQUE (wall-WALL)	demonio-BUENO (devil-GOOD)	latín-INGLÉS (Latin-ENGLISH)
hambre-APETITO (hunger-APPETITE)	fondo-SUPERFICIE (bottom-SURFACE)	nariz-DEDO (nose-FINGER)
broma-BURLA (joke-JEST)	duro-TIERNO (hard-TENDER)	pueblo-ALDEA (town-VILLAGE)
punta-PINCHO (point-PRICK)	negro-CLARO (black-CLEAR)	calle-AVENIDA (street-AVENUE)
lluvia-AGUACERO (rain-SHOWER)	centro-BORDE (centre-BORDER)	ciencia-ARTE (science-ART)
cuello-PESCUEZO (neck-NECK)	verdad-ERROR (truth-ERROR)	puerta-TECHO (door-CEILING)
humo-VAPOR (fume-STEAM)	guerra-TREGUA (war-TRUCE)	brazo-CODO (arm-ELBOW)
tienda-COMERCIO (shop-STORE)	sabio-INCULTO (sage-INCULT)	mesa-ARMARIO (table-CLOSET)
ramo-MANOJO (bunch-HANDFUL)	éxito-DERROTA (success-DEFEAT)	norte-ESTE (North-EAST)
lucha-COMBATE (fight-COMBAT)	sombra-CLARIDAD (shade-CLARITY)	libro-CUADERNO (book-NOTEBOOK)
hoja-FOLIO (sheet-FOLIO)	salud-MALESTAR (health-DISCOMFORT)	francés-ALEMÁN (French-GERMAN)
autor-CREADOR (author-CREATOR)	duda-CERTEZA (doubt-CERTAINTY)	duque-BARÓN (duke-BARON)

co-occur in natural language (Lowe, 1997; McKoon & Ratcliff, 1992).

Semantic priming and semantic memory

Priming was also observed between word pairs that were semantically, but not associatively, related at very short SOAs (83 ms and longer; Experiment 2). As indicated earlier, it could be the case that semantic priming is just as automatic as associative priming, but it has a slightly slower rise time. It seems that the semantic primes were not processed sufficiently to facilitate responses to the target words at the shortest SOA (66 ms), although it may be of interest to indicate that a pure semantic priming effect was obtained for the "slow" items with that SOA[5]. Furthermore, the lifetime of semantic

[5] To investigate whether some semantic priming effects might occur for the "slow" items at the shortest SOA, we divided the word targets from Experiment 2 into "slow" and "fast" items as a function of the mean reaction time. Since there were 11 word targets per condition and list (66 word targets overall), the five fastest items were considered "fast" items, whereas the five slowest items were considered "slow" items. As a result, the following statistical analyses were based on 60 word targets. The results show that, at the 66-ms SOA, the slow items yield a significant 18-ms priming effect (810 vs 828 ms), $F2(1, 48) = 4.14$, whereas the effect for the fast items is virtually null (1 ms; 721 vs 722 ms).

Table 8. Word-word pairs in Experiments 3 and 4

Associative + semantic pairs	Semantic-only pairs
cara-ROSTRO (face-FACE)	casa-VIVIENDA (house-FLAT)
miembro-PARTE (member-PART)	hijo-VÁSTAGO (son-OFFSPRING)
dama-SEÑORA (dame-LADY)	cambio-PERMUTA (exchange-BARTER)
hoja-PAPEL (sheet-PAPER)	dolor-MOLESTIA (pain-DISCOMFORT)
núcleo-CENTRO (nucleus-CENTRE)	jardín-VERGEL (garden-ORCHARD)
deber-OBLIGACIÓN (duty-OBLIGATION)	hambre-APETITO (hunger-APPETITE)
error-FALLO (error-MISTAKE)	broma-BURLA (joke-JEST)
azar-SUERTE (hazard-CHANCE)	lluvia-AGUACERO (rain-SHOWER)
muro-PARED (wall-WALL)	cuello-PESCUEZO (neck-NECK)
joven-VIEJO (young-OLD)	humo-VAPOR (fume-STEAM)
venta-COMPRA (sale-PURCHASE)	tienda-COMERCIO (shop-STORE)
odio-AMOR (hate-LOVE)	ramo-MANOJO (bunch-HANDFUL)
noche-DíA (night-DAY)	lucha-COMBATE (fight-COMBAT)
éxito-FRACASO (success-FAILURE)	orden-CAOS (order-CHAOS)
negro-BLANCO (black-WHITE)	prisa-CALMA (hurry-CALM)
calor-FRÍO (heat-COLD)	final-COMIENZO (end-INITIATION)
curva-RECTA (curve-STRAIGHT LINE)	lujo-POBREZA (luxury-POVERTY)
guerra-PAZ (war-PEACE)	valor-COBARDÍA (courage-COWARDICE)
verdad-MENTIRA (truth-LIE)	premio-SANCIÓN (prize-SANCTION)
causa-EFECTO (cause-EFFECT)	sabio-INCULTO (sage-INCULT)
verso-PROSA (verse-PROSE)	sombra-CLARIDAD (shade-CLARITY)
suma-RESTA (sum-SUBTRACT)	salud-MALESTAR (health-DISCOMFORT)
pobre-RICO (poor-RICH)	nieto-HERMANO (grandson-BROTHER)
mesa-SILLA (table-CHAIR)	templo-MUSEO (temple-MUSEUM)
perro-GATO (dog-CAT)	latín-INGLÉS (Latin-ENGLISH)
rayo-TRUENO (lightning-THUNDER)	pueblo-ALDEA (town-VILLAGE)
diente-MUELA (tooth-MOLAR)	calle-AVENIDA (street-AVENUE)
nariz-BOCA (nose-MOUTH)	puerta-TECHO (door-CEILING)
rosa-CLAVEL (rose-PINK)	libro-CUADERNO (book-NOTEBOOK)
julio-AGOSTO (July-AUGUST)	duque-BARÓN (duke-BARON)

information seems to be quite short, since the results with the single-presentation technique show that semantic primes are quite effective at influencing the recognition of the target word at a brief RSI (200 ms: 21-ms effect) but not at a long RSI (1,750 ms: 7-ms effect).

However, one could wonder whether the semantic priming effects at SOAs of 83 ms (and longer) with the masked priming technique are still due to automatic processes. Recent research in our laboratory has found that associative priming effects do not appear to be influenced by the proportion of associated pairs at SOAs of 166 ms or briefer (Perea & Rosa, 2002), which strongly suggests that the obtained effects are not influenced by participants' strategies. Instead, it seems more reasonable to assume that activation in the semantic system would be slower to spread than in the lexical system (in a traditional spreading activation account) or that the rise time of activation is faster for co-occurrence based learning (i.e., associative priming) rather than for semantic overlap (see Alario, Segui, & Ferrand, 2000). For instance, in a recent picture naming experiment at a short SOA (114 ms), Alario et al. (2000) found a different rise time of activation for associative and semantic pairs. Specifically, they found a reliable (inhibitory) effect for associatively related pairs (glove-HAND), but not for nonassociated, semantically related pairs (horse-ZEBRA).

If our view with respect to associative/semantic priming effects is correct, we should explain why several studies have found "pure" semantic priming effects with the masked priming technique at very brief SOAs (e.g., Perea & Gotor, 1997; Williams, 1996)[6]. There seems to be no reason why the processing of the prime should not continue after termination of the prime, perhaps even overlapping the lexical processing of the target to an appreciable degree (see Forster et al., 1987; Kiger & Glass, 1983). If this reasoning is correct, the main issue is whether the associative/semantic information from the prime can be coded quickly enough to speed recognition of the subsequent target word. In other words, the effectiveness of the primes depends not only on the prime duration, but also on the rapidity of processing of the prime and the target. In this way, the results from Experiment 2 suggest that semantic primes were not processed sufficiently to facilitate responses to the "fast" items at the shortest SOA. In other words, longer response times may leave more room for semantic priming to occur (see McRae & Boisvert, 1998; Williams, 1996, for a similar argument). This interpretation is also compatible with the fact that translation priming with masked primes is stronger when the prime is in L1 and the target in L2 (see Gollan, Forster, & Frost, 1997; Grainger & Frenck-Mestre, 1998; Williams, 1994).

[6] It may be of interest to note that Williams (1996) used a laptop with a gas-plasma display to present the stimuli (instead of a conventional display unit). Thus, it is likely that some trace of the prime remained on the screen for more than the specified 50 ms. If that was the case, the results reported by Williams would be compatible with those found in Experiment 2.

As we indicated in the Discussion section of Experiment 2, the fact that the size of the semantic priming effect (and the time course of activation) was similar for the different types of semantic relationships (synonyms, antonyms, and category coordinates) seem to pose some problems for the spreading activation or connectionist accounts (Experiments 1 and 2; see also Hodgson, 1990; Williams, 1996). After all, synonyms are judged as more ''similar'' than category coordinates, and these two accounts predict a greater semantic priming effect for highly similar words. One alternative account to explain the semantic priming effect with visible primes is a post-access ''integration'' (or context-verification) account, in which the final selection of the target word in the candidate set could depend on whether or not it is congruent with the ''context'' provided by the prime word (e.g., by lowering the threshold for a ''yes'' response, Norris, 1986; see also de Groot, 1984; Snow & Neely, 1987, for similar accounts). This integration process might operate automatically over the output of the lexical access system, which appears consistent with a perspective of the linguistic processing system as a whole (see Fodor, 1983; Hodgson, 1991). In addition, this integration process would need to extend over entire semantic fields (Forster, 1979) to handle the fact that synonyms, antonyms, and category-coordinates yield similar time courses of priming (see Hodgson, 1991).

Over the past years, the principal alternative to the spreading activation and connectionist accounts has been the compound cue model (e.g., McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988, 1994). This model assumes that participants can use a compound cue consisting of both the prime and target in the access to lexical memory. Lexical decision responses depend on the familiarity of the compound cue, so that familiar cues (associatively/semantically related word pairs, e.g., memory-MIND) will be responded to faster than unfamiliar cues (unrelated word pairs, e.g., family-MIND). The only condition is that the prime and the target enter the compound cue. The familiarity of the compound cue depends basically on the co-occurrence of the word pairs and the semantic relatedness rather than the associative strength as measured from free-production associative norms (McKoon & Ratcliff, 1992). This fact might explain the similar priming effects for semantic-only and associative + semantic pairs at SOAs of 83 ms and longer. However, how can the model explain the presence of an associative priming effect at the shortest SOA (66 ms)? After all, masked primes with a 66-ms SOA are hardly visible, and they may not enter the compound cue. Probably, a ''spreading activation'' mechanism among lexical nodes that are strongly associated when the prime does not enter the compound cue is needed, but that would probably violate the spirit of the compound cue model (see Neely, 1991, for a similar argument).

In sum, reality of associative/semantic priming effects in visual word recognition is highly complex. Models that propose only one kind of mechanism to explain associative/semantic priming effects cannot readily accommodate the present results. Instead, our results are best interpreted by a ''hybrid'' model that combines the properties of ''spreading activation'' and ''integration'' mechanisms in a similar way to the model of Neely, Keefe, and Ross (1989; Neely, 1991). At SOAs of about 60 ms, priming would occur automatically via spreading activation along associated nodes in the internal lexicon (i.e., the effects could occur at the lexical level). At longer SOAs, the integration/semantic component may play a role, since the prime will be fully processed on most trials. In this light, it is important to independently manipulate associative and purely semantic relations, which are confounded in most priming studies. Undoubtedly, more research needs to be done to clarify the role of associative strength (as measured by word-association norms) versus co-occurrence statistics (see Lowe, 1997; Lund et al., 1998) as well as the role of different types of semantic relation in visual word recognition and reading.

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Word-word pairs in Experiments 1–4

Tables 6, 7, and 8.

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