TITLE: The co-occurrence frequency evaluated with large language corpora acts as a boost in semantic priming effects

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Running Head: Co-occurrence frequency in semantic networks

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Abstract

In recent decades, many computational techniques have been developed to analyze the contextual usage of words in large language corpora. The present study examined whether the co-occurrence frequency obtained from large language corpora might exert a boost in purely semantic priming effects. Two experiments were conducted: one with conscious semantic priming, the other with subliminal semantic priming. Both experiments contrasted three semantic priming contexts: an unrelated priming context and two related priming contexts with word pairs that are semantically related and that co-occur either frequently or infrequently. In the conscious priming presentation (166-ms SOA), a semantic priming effect was recorded in both related priming contexts, which was greater with higher co-occurrence frequency. In the subliminal priming presentation (66-ms SOA), no priming effect was shown, regardless of the related priming context. These results highlighted that co-occurrence frequency boosts pure semantic priming effects and are discussed with reference to models of semantic network.

151 words

Keywords: semantic priming, co-occurrence frequency, purely semantic relation, visual lexical decision task

Introduction

The general issue of meaning knowledge concerns on how semantic networks are organized in memory and how the statistical learning (called also distributional learning) can shape the organization of semantic representations. It is well known that infants, children, and adults use statistical regularities to encode, process, and retrieve linguistic information (Aslin & Newport, 2008; Ellis, 2002; Perruchet & Pacton, 2006; Wells, Christiansen, Race, Acheson, & McDonald, 2009). In particular, the probabilistic knowledge is exploited by 8-month-old infants to perform word segmentation during language acquisition (Saffran, Aslin, & Newport, 1996) and by primary and secondary school students to learn past participle inflections in written French (Negro, Bonnotte, & Lété, 2014). In the last decades, numerous computational models attempted to learn semantic representations from statistical regularities in the linguistic environment (for a review, Jones, Kintsch, & Mewhort, 2006). It has been shown that the complexity required for building semantic representations is available from the occurrence of words in contexts across large language corpora. Typically, computational models represent words in a high-dimensional semantic space from statistical co-occurrences in text. Thus, they are called Semantic Space Models, or Co-occurrence Models, or Distributional Models (see Sahlgren, 2008, for a discussion of the distributional hypothesis). The most studied and known of them are LSA (Latent Semantic Analysis; Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990; Landauer & Dumais, 1997), HAL (Hyperspace Analogue to Language; Burgess & Lund, 2000; Lund & Burgess, 1996), and BEAGLE (Bound Encoding of the Aggregate Language Environment; Jones, Kintsch, & Mewhort, 2006; Jones & Mewhort, 2007). It is important to note that Semantic Space Models bring out semantic relationships between words thanks to the usage of words in similar contexts across large language corpora. These semantic relationships between words exist even if two words have never co-occurred in the same contextual environment. In this context, the aim of this study is to examine the role that statistical regularities extracted from the linguistic environment still plays in semantic networks in experts. The central question is therefore whether the lexical co-occurrence frequency is encoded in semantic networks and still contributes to strengthen the purely semantic relation built between words in an expert system. In other words, the encoding of lexical co-occurrence frequency in semantic networks could boost the processing of words sharing a purely semantic relation.

To this day, many experimental studies have been conducted to explore the organization of semantic representations in memory (for reviews, Hutchison, 2003; Lucas, 2000). The most studied effect is the so-called "semantic priming effect". In a typical procedure (first designed by Meyer & Schvaneveldt, 1971), a first stimulus, the prime, appears before the presentation of a second stimulus, the target. Then, the effect of prime is observed on responses given to the target, such as lexical decisions. More exactly, the semantic priming effect is measured by comparing performance in two priming contexts: one with semantically related prime-target pairs (e.g., *cat-dog*), and the other with unrelated prime-target pairs (e.g., *glass-dog*). This refers to the observation that a target word is recognized faster when it is preceded by a semantically related prime rather than by an unrelated prime. The origin of semantic priming effect has been debated, for a long time, to disentangle whether semantic priming effect is the result of semantic overlap or simply association strength between the prime and the target. At present, it appears that there is facilitation for prime-target pairs that share a purely semantic relation even if they have a weak lexical association strength and for prime-target pairs that share a purely associative relation even if they have a weak semantic similarity (see Ferrand & New, 2003). The degree of lexical association strength for word pairs is traditionnally taken from word association norms, constructed by giving people a cue such as *dog* and asking them to respond with the first word coming to mind (e.g., *cat*). For instance, while the French word association database from Ferrand and Alario (1998) comprises 366 cues, which are all names of concrete objects, other databases can comprise more cues, such as the Dutch word association database from De Deyne, Navarro, and Storms (2013), comprising 12,000 cues or the English word association databases from the Edinburgh Associative Thesaurus (Kiss, Armstrong, Milroy, & Piper, 1973), which contains responses to 8211 cues, and from the University of South Florida Word Association norms (Nelson, McEvoy, & Schreiber, 2004), which contains responses to 5019 cues. Nonetheless, word association databases are smaller than the average reader's vocabulary, leading that every word is not found in a free-association norm. It is also striking to consider the fact that each participant provides one response (Ferrand & Alario, 1998; Kiss, Armstrong, Milroy, & Piper, 1973; Nelson, McEvoy, & Schreiber, 2004) or three responses (De Deyne & Storms, 2008; De Deyne, Navarro, & Storms, 2013) to each cue word. This induces that weak or intermediate associative links between two words cannot be easily extracted from word association norms.

In using free-association norms, some authors also observed mediated priming effects (e.g., Chwilla & Kolk, 2002; McKoon & Ratcliff, 1992). These latter priming effects refer to facilitation for prime-target pairs that are only indirectly associated in semantic memory (e.g., *deer-vegetable*). In those cases, a mediator (e.g., *animal*) shares a strong associative relation with the prime (e.g., *deer-animal*) and with the target (e.g., *animal-vegetable*). Interestingly, Chwilla and Kolk (2002) and McKoon and Ratcliff (1992) have proposed that the frequency of co-occurrence between prime-target pairs might explain mediated priming effects. Indeed, it was not asked to focus attention on the phrasal contiguity between words during free-association production norms. As a consequence, the measures of word association norms do not directly reflect the real co-occurrence frequency between linguistic events. Moreover, word association norms are totally subjective and responses in word association norms may partly depend on the content of the word list, because participants can receive only a limited number of stimuli. To test whether the frequency with which the prime and the target co-occurred gave rise to mediated priming effects, Chwilla and Kolk (2002) removed all prime-target pairs that co-occurred in a Dutch newspaper (around 5 million words) within a window of thirteen words. Then, they performed a new analysis of their three-step priming effects (i.e., involving two mediators between the prime and the target) found in a double visual lexical decision task. This analysis on remaining prime-target pairs (not directly associated and unrelated pairs) revealed again a mediated priming effect, suggesting that the frequency with which the prime and the target co-occurred did not cause the mediated priming effects described in this study. Instead, a more global measure of semantic similarity taken from the LSA model on prime-target pairs of the study of Chwilla and Kolk (2002) accounted for the observation of mediated priming effects. Furthermore, following the same hypothesis as Chwilla and Kolk (2002), McKoon and Ratcliff (1992) had already investigated the role of co-occurrence frequency across large samples of written language but in a semantic priming paradigm (see Experiment 3 in McKoon & Ratcliff, 1992). In that case, they manipulated four semantic priming contexts, one unrelated and three related: prime-target pairs with high probability of production in free-association norms, prime-target pairs with high co-occurrence frequency, and prime-target pairs with low co-occurrence frequency. McKoon and Ratcliff (1992) thus dichotomized lexical co-occurrence frequency into two categories, high and low values, calculated from samples of the Associated Press newswire (6 million words) within a window of six consecutive words. In a double visual lexical decision task, the greatest priming effect was obtained for highly associated prime-target pairs. A priming effect was also found for prime-target pairs that highly co-occurred, whereas there was no priming for pairs that lowly co-occurred. From the latter finding, MacKoon and Ratcliff (1992) concluded that lexical co-occurrence frequency appeared as a valuable predictor of priming effects. However, the degree of semantic relatedness of each prime-target pair obtained from a seven-point scale gave rise to different scores between the three related priming contexts, with the highest score for prime-target pairs highly associated in free-association norms (5.9), an intermediate score for pairs that highly co-occurred (4.9), and the lowest score for pairs that lowly co-occurred (3.9). Thus, this made difficult the interpretation of priming effects observed in the study of McKoon and Ratcliff (1992). To sum up, although McKoon and Ratcliff (1992) and Chwilla and Kolk (2002) attempted to examine whether lexical co-occurrence frequency might account for priming effects, the question concerning the role of lexical co-occurrence frequency in the structure of semantic memory remains still unsolved.

To this aim, we adopted the same approach as McKoon and Ratcliff (1992) in dichotomizing lexical co-occurrence frequency into two categories, high and low values, but in controlling the semantic relatedness of prime-target pairs. To make sure that using word co-occurrence frequencies established from large language corpora offers a real index at which individuals are exposed daily and best reflects language usage, we employed the corpora of film dialogue (New, Brysbaert, Veronis, & Pallier, 2007). More precisely, we examined whether lexical co-occurrence frequency might contribute to strengthen the purely semantic relation built between words in an expert system. We hypothesized that lexical co-occurrence frequency encoded in semantic networks could boost the processing of words sharing a purely semantic relation.

According to the meta-analyses describing semantic priming effects (Hutchison, 2003;

Lucas, 2000), there are many divergences between studies manipulating the time interval that elapses between the beginning of the prime and that of the target, called the stimulus-onset asynchrony or SOA (Neely & Keefe, 1989; Neely, 1991), and also examining priming effects in more drastic prime presentation conditions, like in subliminal presentation. For instance, the results of Lucas's (2000) meta-analysis indicated that purely semantic priming can occur at SOAs less than 250 ms, without high lexical association strength, for varied types of purely semantic relations. On the contrary, Hutchison (2003) underlined that semantic priming is not observed at SOAs less than 250 ms, without high lexical association strength. Now, if we consider priming studies in subliminal presentation, Kiefer (2002) found semantic priming effects for semantically related pairs at a 67-ms SOA with a 33.5-ms prime duration. A random pattern mask consisting of 10 letters was presented before and after the prime. As well, Balota, Yap, Cortese, and Watson (2008) observed semantic priming effects at a 42-ms SOA (which was also the prime duration). However, in this study, related prime-target pairs were selected from word association norms and only one mask composed of hashes was presented before the prime. Contrary to these studies, Bueno and Frenck-Mestre (2008) conducted masked priming experiments and no semantic priming effect has been demonstrated. In this study, the authors manipulated two types of semantically related prime-target pairs by contrasting strong associates (selected according to both a pretest and published French association norms, see Ferrand & Alario, 1998) and non-associates (adapted from the stimuli of McRae & Boisvert, 1998). When the prime was subliminally presented with a forward mask (13 hash marks) for 500 ms before the prime, the semantic priming effect was not shown for both strong associates and non-associates at either 28-ms or 43-ms prime duration, and from 14 to 57 msec backward mask duration between the prime and the target (see Experiment 5). Similarly to Bueno and Frenck-Mestre (2008), de Wit and Kinoshita (2014) showed that masking the prime eliminates the semantic priming effect in a lexical decision task.

Our main question of interest was to explore whether lexical co-occurrence frequency encoded in semantic networks could boost the processing of words sharing a purely semantic relation. Moreover, in light of the numerous divergences between previous priming studies in conscious and subliminal presentation, we aimed to examine whether the semantic priming effects generated by a purely semantic relation and perhaps also influenced by the degree of lexical co-occurrence frequency might depend on the mode of presentation. To this end, we conducted two experiments to examine the role of co-occurrence frequency in purely semantic priming in masked and unmasked priming conditions in a visual lexical-decision priming task. In Experiment 1, the unmasked prime was consciously presented at a 166-ms SOA, whereas in Experiment 2, the masked prime was unconsciously exposed to participants at a 66-ms SOA. In both experiments, the priming context was manipulated by contrasting an unrelated context and two semantically related contexts, wherein the prime and the target always shared a purely semantic relation and co-occurred either frequently or infrequently in large language corpora of films. Since lexical co-occurrence frequency could be encoded in semantic networks, we predicted a semantic priming effect in the two semantically related contexts and a boost of the semantic priming effect when the prime and the target co-occurred frequently.

Experiment 1: Unmasked visual lexical-decision priming

Method

Participants. Thirty-six healthy, native French speakers with normal or corrected-to-normal vision participated in this experiment. They were recruited at the University of Lille. The participants included 31 women and 5 men, with a mean age of 20.7 (range: 17-27 years). All participants signed a written consent form before beginning the experiment, which was conducted in accordance with the Declaration of Helsinki. The experiment was approved by the Research Ethics Committee of the University of Lille.

Material. We selected 90 word targets, each associated with three priming contexts: semantically related with a high co-occurrence frequency (high CF) such as for example, *garage-voiture* (garage-car), semantically related with a low co-occurrence frequency (low CF) such as *traffic-voiture* (traffic-car), and semantically unrelated (UR), such as *ours-voiture* (bear-car). The complete set of French stimuli is listed in the Appendix A. The purely semantic relation between the prime and the target varied as much as possible among synonymy (e.g., *douce-tendre*, sweet-tender), antonymy (e.g., *paradis-enfer,* heaven-hell), categorical (e.g., natural: *sel-poivre,* salt-pepper, and artificial: *couteau-fourchette*, knife-fork), and script (e.g., *fusil-chasse,* rifle-hunting) relations, in order to prevent checking strategies based on a particular type of purely semantic relations. To rule out a differential impact of the degree of semantic relatedness between the prime and the target in the two semantically related priming contexts, one hundred and twenty participants, not included in the priming task, were asked to rate the degree of semantic relatedness on a five-point scale (from 0 = unrelated to 4 = strongly related; for a similar approach, Li, Zhao, & Lu, 2014). In total, three hundred and sixty prime-target pairs were evaluated across the whole of participants. Every participant received one hundred and twenty prime-target pairs, among which there were semantically related and unrelated pairs. The two semantically related priming contexts have been selected such that the prime-target pairs did not significantly differ in the degree of semantic relatedness, $t(89) = 0.04$, $p > .2$ (high CF: 3.52, low CF: 3.48). The other critical factor of this study, co-occurrence frequency, was collected from large language corpora of film subtitles (New, Brysbaert, Veronis & Pallier, 2007), accessible on the *Lexique* website (www.lexique.org). These large language corpora of film subtitles were composed of a total of 50.4 million words. A window of ten words taking into account the function and content words was used, because it is the longest available from these corpora. To separate the co-occurrence of a pair of words from their base frequencies, we calculated pointwise mutual information[1] for each word pair as a measure of co-occurrence frequency (for a similar approach, see Van Petten, 2014). Co-occurrence frequency did not significantly differ between the semantically related pairs with a low co-occurrence frequency and the semantically unrelated pairs, $t(89) = -1.36$, $p > .2$ (low CF: 12.66, UR: 13.06). As expected, the frequently co-occurring semantically related pairs (high CF) differed from the infrequently co-occurring semantically related pairs (low CF), $t(89) = 15.38$, $p < .001$ (high CF: 16.22). The psycholinguistic properties of primes in the three priming contexts were matched for cumulative lexical frequency, word length, and number of orthographic neighbors (estimated from the *Lexique* website, New et al., 2007, see Table 1). Word targets had a mean cumulative lexical frequency of 142 occurrences per million words and a mean word length of 5.8. For the purposes of the task, 90 word-pseudoword pairs were added and were not further analyzed. Pseudoword targets were orthographically legal and were constructed by replacing a letter in French words other than those in the experimental set. The word and pseudoword targets were matched for length. From all word-word pairs, three lists were constructed, so that each target was associated with all three priming contexts across participants, but was presented only once per participant. Each list was composed of 180 prime-target pairs: 90 word-word and 90 word-pseudoword pairs. The 90 word targets were preceded by 30 semantically related primes with a high co-occurrence frequency, 30 semantically related primes with a low co-occurrence frequency, and 30

[1] The pointwise mutual information is defined by the following formula: $log_2\ ((pt * corpus\ size)/(p * t * span))$, with *pt* the co-occurrence count for prime and target words, *corpus size* the total number of words *p* the overall frequency of the prime in the same corpus, *t* the overall frequency of the target, and *span* the window size for the co-occurrence count.

semantically unrelated primes with a low co-occurrence frequency.

< Insert Table 1 here >

Procedure. Each participant was randomly assigned to one list. The 180 total trials were divided into two blocks of 90 trials each. Trial order within each block was randomized and a break was provided between the blocks. The primes and the targets, in lowercase, were presented in white font against a black background on a computer monitor synchronously with the screen refresh (refresh rate: 16.67 ms). In each trial, participants were first presented with a fixation cross for 500 ms, followed by a prime word for 150 ms. After the prime presentation, a black screen was presented for 16 ms, creating a SOA of 166 ms. Thereafter, the target stimulus, either a real word or a pronounceable pseudoword, was displayed and remained on the screen until the participants' response. Participants were instructed to indicate, as quickly and accurately as possible, whether the target stimulus was a real word or not. Responses were given by pressing one of two buttons on a button box (the button responses were assigned based on the participants' handedness). The inter-trial interval (a black screen) lasted 1500 ms. Before the experimental task, participants first received instructions and 12 practice trials. It took approximately fifteen minutes to complete the task.

After the priming task, participants realized a prime visibility test during which they were instructed to perform a new lexical decision task on the primes. The prime-target pairs used in the main experiment and new prime-target pseudoword pairs were shown to the participants. This informed us on the conscious level of prime visibility during the priming task. The sequence of events and stimulus parameters were identical with the priming task. Each participant received 90 word-word pairs, 90 word-pseudoword pairs, 90 pseudoword-word pairs, and 90 pseudoword-pseudoword pairs. Participants had to decide whether the prime was a real word or not and were instructed to give the first response that came to mind. The instructions stressed accuracy over response speed. The prime visibility task, consisting of 12 practice prime-target pairs and 360 randomly presented experimental prime-target pairs, took approximately fifteen minutes. The hit rates of prime recognition (mean hit rates: 0.93) were substantially higher than the false alarm rates (mean false alarm: 0.09). At the end of the prime visibility test, all participants reported that they had consciously recognized the letters of primes.

Results

For the analyses of priming data, incorrect responses (2.9%) and decision latencies smaller than 200 ms or larger than 1000 ms (3.2%) were excluded. The mean lexical decision latencies and error percentages from the participant analysis are presented in Appendix B. A linear mixed-effects model approach with participants and items specified as crossed random factors (Baayen, Davidson, & Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013) was used to analyze lexical decision latencies as a function of priming context. Models included the full random effect structure with random intercepts and slopes for both participants and items. Augmented and reduced models (i.e., including or not the fixed effect of interest) were compared using -2LogLikelihood Ratio (distributed as χ^2 with degrees of freedom equal to the number of parameters added). Analyses were performed with the *lme4 1.1-12* package of R version 3.2.5. The analysis of lexical decision latencies revealed an effect of priming context [$\chi2(2) = 19.72$, $p < .001$]. Latencies were 23 ms shorter for semantically related pairs with a high co-occurrence frequency than unrelated pairs [estimate = 22.63, $t = 5.07$, SE = 4.47, $p < .001$]. Likewise, latencies for semantically related pairs with a low co-occurrence frequency were 12 ms shorter compared to unrelated pairs [estimate = 12.25, $t = 2.73$, SE = 4.49, $p < .001$]. To evaluate the size of the difference in priming effect between each of the two semantically related contexts and the unrelated context, a linear hypothesis from the augmented model including the fixed effect of interest was performed with the *multcomp 1.4-5* package of R version 3.2.5. This analysis showed that the priming effect was 10 ms stronger in semantically related pairs with a high co-occurrence frequency in comparison with semantically related pairs with a low co-occurrence frequency [estimate = 10.39, z = 2.29, SE = 4.53, p < .05]. Following the same linear mixed-model approach, the analysis of errors did not show any effect of priming context, [$\chi 2(2) = 3.79$, p = .15].

Experiment 2: Masked visual lexical-decision priming

Method

Participants. Thirty-three healthy native French speakers with normal or corrected-to-normal vision took part in this experiment and had not participated in Experiment 1. They were recruited at the University of Lille. They included 30 women and 3 men, with a mean age of 20.7 (range: 17-25 years). As in Experiment 1, all participants signed a written consent form before beginning the experiment, which was conducted in accordance with the Declaration of Helsinki. The experiment was approved by the Research Ethics Committee of the University of Lille.

Material and Procedure. The stimulus sets and tasks were identical to Experiment 1. Contrary to Experiment 1, the prime was masked and the SOA was shorter in Experiment 2, leading to a subliminal presentation of the prime. The choice of a short prime duration of around 50 ms in Experiment 2 was based on previous studies (Diependaele, Sandra, & Grainger, 2005; Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Kouider & Dupoux, 2001) suggesting that this duration is optimal for creating a subliminal stimulus presentation. More precisely, in Experiment 2, participants were first presented with a forward mask consisting of 10 hash symbols (#) for 500 ms, followed by a prime word, which was shown for 50 ms. Next, a random pattern backward mask, composed of 8 capital consonants with no orthographical overlap in letters between the prime and the target, was presented for 16 ms. Thereafter, as in Experiment 1, the target stimulus was displayed and the task was to indicate whether the target was a word or not.

After this task, participants performed a prime visibility test by judging the lexicality on the primes (the same stimuli as Experiment 1 but under the experimental procedure of Experiment 2). Four additional participants to those already mentioned were excluded, since they reported that they had consciously recognized the letters of primes. All included participants declared that they had never perceived one or several letters of primes. They had mean hit rates of 0.51 and mean false alarm rates of 0.47.

Results

For the analyses of priming data, incorrect responses (3.4%) and decision latencies smaller than 200 ms or larger than 1000 ms (2.6%) were excluded. The mean lexical decision latencies and error percentages from the participant analysis are presented in Appendix B. As with Experiment 1, a linear mixed-effects model approach was used to analyze lexical decision latencies as a function of priming context. The analysis of lexical decision latencies did not reveal any effect of priming context [$\chi 2(2) = 2.05$, $p > 0.2$]. As well, the analysis of errors did not show any effect of priming context [$\chi 2(2) = 0.01$, $p > 0.2$].

Discussion

Two semantic priming experiments were conducted with conscious and subliminal prime presentations while manipulating the co-occurrence frequency between word pairs, as determined from large language corpora of films. To our knowledge, this is the first study showing a boost of the semantic priming effect when primes and targets co-occurred frequently in comparison with prime-target pairs co-occurring lowly. More precisely, in the conscious priming presentation (166-ms SOA), a semantic priming effect was recorded in both semantically related priming contexts. Crucially, the semantic priming effect was greater with prime-target pairs having higher co-occurrence frequency. In the subliminal priming presentation (66-ms SOA), no semantic priming effect was observed, regardless of the related priming context.

Although semantic priming effects with conscious exposure are robust, it appears that semantic priming effects with subliminal exposure seem to be unstable and difficult to reproduce (see for a similar conclusion, Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006). The fact that the semantic priming effect was eliminated when the primes were subliminally presented is consistent with the previous findings of Bueno and Frenck-Mestre (2008) and those of de Wit and Kinoshita (2015). This difficulty to replicate semantic priming effects with subliminal prime presentation does not seem to be explained by the origin of semantic priming effect. For instance, Bueno and Frenck-Mestre (2008) and Balota, Yap, Cortese, and Watson (2008) used related prime-target pairs selected from word association norms, their findings were however completely divergent. Whereas Balota, Yap, Cortese, and Watson (2008) found semantic priming effect, Bueno and Frenck-Mestre (2008) did not state it. Using a backward mask in the study of Bueno and Frenck-Mestre (2008) could be one methodological aspect to account for the discrepancy of findings with Balota and colleagues (2008). Moreover, as revealed by de Wit and Kinoshita (2015), the disappearance of semantic priming effects with subliminal exposure would be also task-dependent. Whereas masked and unmasked primes produced semantic priming effects in a semantic categorization task, presenting masked primes eliminates semantic priming effect in a lexical decision task. Taken together, the weak degree of spreading activation across semantic networks, induced either by the quick presentation of primes, or by the interference between the prime and the backward mask, or by the non-relevant task with respect to semantic networks would explain the difficulty to obtain semantic priming effects in some circumstances.

The main finding of our study is a boost of the semantic priming effect when the primes and the targets co-occurred frequently in the conscious priming presentation. Interestingly, it appeared that controlling the degree of semantic relatedness in two semantically-related prime-target pairs made possible to observe a semantic priming effect in both semantically related priming contexts in which the primes and the targets co-occurred either frequently or infrequently and greater semantic priming effect for prime-target pairs having high co-occurrence frequency. Consistent with the study of MacKoon and Ratcliff (1992), lexical co-occurrence frequency constitutes a valuable parameter of semantic priming effects. More exactly, our findings confirm that lexical co-occurrence frequency is encoded in semantic networks in an expert system. This study thus provides new lights on the organization of semantic representations. To this day, it is assumed that the learning of semantic representations is available from statistical regularities in the linguistic environment. This assumption comes from computational models, called semantic space models, which are able to learn semantic representations from the occurrence of words across large language corpora (for a review, Jones, Kintsch, & Mewhort, 2006). One can ask whether high-dimensional semantic spaces learnt by semantic space models can account for human data in semantic, associated, and mediated priming experiments such as in a lexical decision task. For instance, Günther, Dudschig, and Kaup (2015) conducted two semantic priming experiments in which prime-target pairs were selected according to the Latent Semantic Analysis model (LSA, Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990; Landauer & Dumais, 1997). The authors hypothesized that higher values of LSA semantic similarity should produce higher semantic priming effects. In LSA model, a word-by-document frequency matrix is constructed from a corpus and dimensional vectors represent the distributions of words across the corpus. If words often occur in the same contexts, they tend to have similar vectors. It is assumed that the more similar word vectors, the more similar the semantic representations would be. Computing the similarity of vectors in one word pair gives the degree of semantic similarity for this word pair represented in the semantic space. Günther, Dudschig, and Kaup (2015) found that values of LSA semantic similarity predicted semantic priming effects. On the contrary, in using a regression analysis, values of LSA semantic similarity failed to predict reaction times at item level in the study of Hutchison, Balota, Yap, Cortese, and Watson (2008). However, these authors performed post-hoc analyses on their associated priming data without controlling the distribution of LSA semantic similarities across prime-target pairs. Other authors also attempted to compare the divergences of computational models to describe human data in semantic, associated and mediated priming experiments (Jones, Kintsch, & Mewhort, 2006; Lowe & McDonald, 2000; McDonald & Lowe, 1998). Particularly, Jones et al. (2006) reported that LSA and BEAGLE (Bound Encoding of the Aggregate Language Environment; Jones, Kintsch, & Mewhort, 2006; Jones & Mewhort, 2007) are able to replicate mediated priming effects (also found by Lowe & McDonald, 2000), but it is not the case for HAL (Hyperspace Analogue to Language; Burgess & Lund, 2000; Lund & Burgess, 1996). More generally, LSA focusing on contextual co-occurrence overestimates the strength of associative relationships in comparison with human data. Contrary to LSA, HAL develops stronger relationships between words when they share the same positional similarity within a moving window. Consequently, HAL creates stronger relationships between words sharing semantic relations than associative relations. In contrast, BEAGLE takes into account two types of information, contextual similarity and order similarity and incorporates it in a composite representation. The combination of these two types of information better explains human data in a variety of semantic, associated and mediated priming experiments. In addition, McDonald and Lowe (1998) reported that the encoding of temporal co-occurrence information within a small window (around 6 words) helps to replicate particular human data such as an associative boost for strong associates. Whatever the nature of semantic space models, they capture deep semantic and associative relations and not just a simple co-occurrence frequency measure. For instance, Landauer, Foltz, and Laham (1998) mentioned that high values of LSA semantic similarity are found for words that never occurred together in the same document. More precisely, Jones, Kintsch, and Mewhort (2006) indicated that 70% of a word's nearest neighbours according to the LSA are words never occurred in the same document. Hence, the finding of a boost due to co-occurrence frequency in purely semantic priming effects provides different contributions than semantic space models in regard to the structure of semantic memory.

We discuss thereafter our findings in the framework of semantic models (Collins & Loftus, 1975; and Plaut & Booth, 2000). According to the spreading-activation theory of Collins and Loftus (1975), semantic memory is composed of a network of interconnected nodes. Following this model, there are two separate networks: one purely lexical with connections built through repeated occurrence between words, the other purely semantic, with connections encoded according to meaning relation between words. Even though this model does not provide specific predictions regarding the time course of spreading activation across the two separate networks, it is usually assumed a fast and automatic spreading activation. This latter assumption thus is not consistent with our findings, since no semantic priming effect was observed in the subliminal priming presentation. By contrast, in the distributed connectionist model developed by Plaut (Plaut, 1995; Plaut & Booth, 2000), one network is conceptualized in which the activation spreads between linguistic units in two layers, one orthographic and one semantic, connected to varying degrees of strength via a hidden layer. Thus, each concept is represented by a particular pattern of activity over a large number of processing units. When reading a word, units cooperate and compete across weighted connections until the whole network settles into a stable pattern of activity representing the meaning of the word. Interestingly, this model distinguishes between the purely semantic relation (limited to the categorical one) and the lexical co-occurrence frequency. More precisely, the lexical co-occurrence frequency is encoded directly in the likelihood that the second word (i.e., the target) follows the first word (i.e., the prime) during training. Plaut (1995) performed simulations of priming effects for each of the two relations at different prime durations. Even though the absolute time scale of the network is arbitrary, Plaut and Booth's model provides opposite predictions relative to the purely semantic priming effects and co-occurrence frequency effects when the prime duration increases. It predicts weak purely semantic priming effects at short SOAs, which grow slightly and then progressively dwindle with increasing SOA. Indeed, with increasing SOA, the cognitive system can process the prime more deeply, accessing semantic features that do not characterize the target, which may delay the decision (e.g., a hat and a coat are both members of the same superordinate category of clothing; both possess similar features, but they also differ in many aspects). Co-occurrence frequency priming effects are also expected to be weak at short SOAs, but to increase with longer SOAs. Indeed, during training, the model learns to make a quick transition from the representation of the prime to that of the target, and the priming effects expand at longer SOAs because the representation produced by the prime becomes progressively accurate. In other words, when the time to process the prime is very brief, it might be difficult to register a pure semantic priming effect as well as a pure lexical co-occurrence frequency effect. With a substantial processing time of the prime, both priming effects might be registered, whereas increasing the processing time of the prime might provoke the disappearance of the pure semantic priming effect but the growth of the pure lexical co-occurrence frequency. In line with these predictions, the subliminal priming presentation with a 66-ms SOA appears as a processing time of the prime not enough long to observe any priming effects in either of the related priming contexts. Then, a longer SOA (166-ms SOA) seem to be a sufficient processing time of the prime to register the two types of priming effects. Indeed, at this SOA, we recorded a priming effect in both the semantic priming context with low co-occurrence frequency (i.e., the pure semantic priming context) and that with high co-occurrence frequency, and more importantly, the co-occurrence frequency boosts the pure semantic priming effect. Therefore, our results are partially within the framework defined by Plaut and Booth's model, which predicted that the cognitive system treats the purely semantic relation and the lexical information given by their co-occurrence frequency and this latter boosts the cognitive system when the time spent on processing is sufficient.

To conclude, this study clearly revealed a boost in semantic priming due to the co-occurrence frequency established from large language corpora of films. Further work should be conducted to investigate the importance of the proximity from which word pairs are selected from large language corpora. It may be that the co-occurrence frequency between words could have a greater impact on spreading activation within the semantic network when these words tend to occur spatially close together (i.e., are frequently separated by a small number of words).

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Table 1

Psycholinguistic properties of the primes according to the priming context

Priming Context	Mean cumulative lexical frequency	Mean word length	Mean number of orthographic neighbors
High CF	47.5	6.4	2.7
Low CF	42.3	6.3	3.6
UR	49.5	6.2	2.9
F-value of ANOVA	$F(2,178) = 0.33$, $p > 0.2$	$F(2,178) = 0.29$, $p > 0.2$	$F(2,178) = 1.07$, $p > 0.2$

Note. CF: co-occurrence frequency; UR: unrelated; cumulative lexical frequency in number of occurrences per million words; word length in number of letters; an orthographic neighbor is any word that can be created by changing one letter of the word and preserving letter positions (Coltheart, Davelaar, Jonasson, & Besner, 1977).

Appendix A

Stimuli used in Experiments 1 and 2

Target	High CF prime	Low CF prime	UR prime
fourchette *fork*	couteau *knife*	assiette *plate*	idée *idea*
peuple *people*	président *president*	langue *language*	rythme *rhythm*
meurtre *murder*	victime *victim*	assassin *killer*	papillon *butterfly*
serrure *lock*	clé *key*	coffre *safe*	oreille *ear*
essence *gasoline*	réservoir *tank*	substance *substance*	orange *orange*
sécurité *security*	contrôle *check*	armée *army*	signature *signature*
beauté *beauty*	jeunesse *youth*	horreur *horror*	océan *ocean*
mode *fashion*	défilé *parade*	façon *way*	manuel *manual*
enfer *hell*	paradis *heaven*	péché *sin*	cercle *circle*
cuisine *kitchen*	salon *living room*	cave *cellar*	peau *skin*
ordre *order*	loi *law*	ménage *housework*	citation *citation*
banque *bank*	chèque *check*	intérêt *interest*	campement *camp*
départ *departure*	retour *return*	fuite *flight*	doute *doubt*
art *art*	musée *museum*	talent *talent*	pays *country*
paix *peace*	espoir *hope*	combat *fight*	poche *pocket*
papa *dad*	fiston *son*	mamie *grandma*	miel *honey*
voiture *car*	garage *garage*	trafic *traffic*	ours *bear*
réalité *reality*	fiction *fiction*	mirage *mirage*	prince *prince*
équipe *team*	joueur *player*	troupe *company*	député *deputy*
tendre *tender*	douce *sweet*	sensible *sensitive*	barbu *bearded*
montagne *mountain*	sommet *top*	volcan *volcano*	porte *door*
adresse *address*	numéro *number*	demeure *residence*	confiance *trust*
pratique *practice*	théorie *theory*	expérience *experience*	famille *family*
fortune *fortune*	gloire *glory*	chance *chance*	pierre *stone*
gorge *throat*	langue *tongue*	poitrine *chest*	chiffon *rag*
radio *radio*	télé *TV*	journal *newspaper*	ambulance *ambulance*
souffrance *suffering*	douleur *pain*	plaisir *pleasure*	souvenir *memory*
muet *dumb*	sourd *deaf*	aveugle *blind*	costaud *tough*
jeu *game*	règle *rule*	pari *bet*	ange *angel*
terre *land*	sol *soil*	domaine *domain*	quart *quarter*
message *message*	appel *call*	mot *word*	vente *sale*
drogue *drug*	dealer *dealer*	poison *poison*	cérémonie *ceremony*
petit *little*	moindre *lesser*	énorme *huge*	superbe *superb*
poivre *pepper*	sel *salt*	piment *pimento*	polka *polka*
canon *cannon*	boulet *cannonball*	revolver *revolver*	énergie *energy*
général *general*	commandant *captain*	maréchal *marshal*	poulet *chicken*
pantalon *pants*	chemise *shirt*	chaussette *sock*	hangar *hangar*
chasse *hunting*	fusil *rifle*	poursuite *chase*	goût *taste*
papier *paper*	feuille *sheet*	carton *card*	champignon *mushroom*
nuit *night*	cauchemar *nightmare*	crépuscule *twilight*	dossier *file*
maître *master*	esclave *slave*	chef *chief*	voleur *thief*
guerre *war*	soldat *soldier*	lutte *fight*	existence *existence*

question *question*	réponse *answer*	énigme *enigma*	valeur *value*
aiguille *needle*	fil *yarn*	pointe *edge*	chameau *camel*
pièce *coin*	monnaie *change*	billet *ticket*	divan *couch*
film *movie*	tournage *shooting*	pellicule *film*	opération *operation*
aide *help*	secours *emergency services*	conseil *advice*	jambe *leg*
innocent *innocent*	coupable *guilty*	suspect *suspect*	veuve *widow*
bureau *desk*	tiroir *drawer*	table *table*	shampoing *shampoo*
route *road*	camion *truck*	sentier *path*	sexe *sex*
pauvre *poor*	riche *rich*	clochard *tramp*	épée *sword*
café *coffee*	thé *tea*	bar *bar*	créature *creature*
honneur *honor*	médaille *medal*	dignité *dignity*	neveu *nephew*
feu *fire*	fumée *smoke*	briquet *lighter*	ruche *hive*
taille *size*	poids *weight*	hauteur *height*	cervelle *brain*
sang *blood*	chair *flesh*	veine *vein*	match *match*
travail *work*	salaire *salary*	tâche *task*	bouton *button*
cadeau *gift*	paquet *package*	présent *present*	public *public*
pluie *rain*	vent *wind*	orage *storm*	faucon *hawk*
vaisseau *vessel*	équipage *crew*	navire *ship*	couloir *corridor*
lumière *light*	ténèbres *darkness*	pénombre *twilight*	sagesse *wisdom*
main *hand*	empreinte *print*	poing *fist*	étranger *stranger*
ami *friend*	ennemi *enemy*	camarade *comrade*	directeur *director*
français *French*	anglais *English*	japonais *Japanese*	fou *crazy*
souris *mouse*	chat *cat*	rat *rat*	dessin *drawing*
immeuble *building*	toit *roof*	bâtiment *building*	angle *angle*
défaite *defeat*	victoire *victory*	échec *failure*	fusion *fusion*
dîner *dinner*	déjeuner *lunch*	repas *meal*	marche *walk/step*
attaque *attack*	défense *defense*	agression *aggression*	prélude *prelude*
vin *wine*	bière *beer*	alcool *alcohol*	pape *pope*
monde *world*	société *society*	foule *crowd*	couleur *color*
état *state*	gouverneur *governor*	nation *nation*	tendance *trend*
doigt *finger*	bague *ring*	pouce *thumb*	piège *trap*
ville *town*	campagne *countryside*	cité *city*	image *image*
pauvreté *poverty*	richesse *wealth*	misère *misery*	marée *tide*
bombe *bomb*	explosion *explosion*	dynamite *dynamite*	cerveau *brain*
peur *fear*	danger *danger*	crainte *fear*	métier *job*
super *great*	génial *awesome*	formidable *wonderful*	enceinte *pregnant*
prison *prison*	cellule *cell*	cachot *dungeon*	article *article*
galaxie *galaxy*	planète *planet*	univers *universe*	chemin *way*
difficile *difficult*	facile *easy*	dur *hard*	rare *rare*
armure *armor*	chevalier *knight*	bouclier *shield*	chariot *carriage*
forêt *forest*	arbre *tree*	bois *wood*	shérif *sheriff*
manteau *coat*	chapeau *hat*	veste *jacket*	carnet *notebook*
sortie *exit*	entrée *entry*	issue *outcome*	crâne *skull*
extérieur *outside*	intérieur *inside*	dehors *outside*	bruit *noise*
mort *dead*	vivant *alive*	défunt *deceased*	spécial *special*
air *air*	souffle *breath*	oxygène *oxygen*	escorte *escort*
nid *nest*	oiseau *bird*	œuf *egg*	syndrome *syndrome*
musique *music*	instrument *instrument*	concert *concert*	action *action*

Note. CF: co-occurrence frequency; UR: unrelated

Appendix B

Mean error percentages and decision latencies (DLs in milliseconds) for participant analysis according to priming context, and priming effects for DL analysis in Experiments 1 and 2

Priming Context	Errors	DLs	Priming effect on DLs
Experiment 1: 166 ms-SOA			
High CF	2.2 (2.5)	558 (73)	22
Low CF	3.5 (3.8)	569 (72)	11
UR	3.1 (3.9)	580 (72)	
Experiment 2: 66 ms-SOA			
High CF	2.8 (4)	598 (62)	8
Low CF	3.8 (4)	600 (62)	6
UR	3.5 (4)	606 (64)	

Note. CF: co-occurrence frequency; UR: unrelated; standard deviation in parentheses