MASKED ASSOCIATIVE PRIMING IN VISUAL WORD RECOGNITION: WHAT MATTERS AND WHAT DOES NOT?

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Abstract

A review of the literature on the masked associative/semantic priming effect shows that the priming effect increases linearly from a prime duration of 30 ms (when it is nearly absent) to a prime duration of 100 ms, and that the size of the effect correlates positively with the association strength between prime and target. These findings are predicted from an elementary activation model according to which the input to the target based on the prime depends on the lexical activity of the prime multiplied by the weight of the prime-target association. Such a model also predicts an effect of prime frequency. In two experiments we failed to obtain such an effect, however. We argue that the most likely explanation of this finding is the fact that high-frequency primes are comparatively less likely to be followed in discourse by their targets than low-frequency primes.

Masked associative priming in visual word recognition: What matters and what does not?

Arguably the two most important effects in word processing are those of word frequency and semantic priming: Words are recognized more efficiently when they occur frequently in discourse and when they are embedded in a related context.

The word frequency effect was first examined properly by Howes and Salomon (1951, Experiment 1). They presented 60 words of varying frequency (as assessed with the Thorndike & Lorge frequency counts). The words were presented with a Gerbrands tachistoscope, starting from a duration of 10 ms and increased with steps of 10 ms. On each trial participants were asked to report the word they thought they saw; they were encouraged to guess. Howes and Salomon observed a curvilinear relationship between the duration thresholds needed to recognize the various words and the frequencies of those words, which was captured well by a logarithmic function.

The semantic priming effect was first reported by Meyer and Schvaneveldt (1971). They presented two letter strings one under another and participants had to decide whether the two strings were words ("yes") or whether any of them made a nonword ("no"). The upper word of the 48 word-word trials came from the Connecticut Free Association Norms, a list of words with their most frequent associates (obtained by asking participants to give the first word that comes to mind upon hearing the stimulus word). Examples of words from this list were BREAD (upon which most participants in the association norm study had answered "BUTTER") and NURSE (with "DOCTOR" as the most frequent associate). The lower word in the Meyer and Schvaneveldt study either was the first associate of the upper word

(BREAD-BUTTER, NURSE-DOCTOR) or the associate of another word (e.g., BREAD-DOCTOR, NURSE-BUTTER). Meyer and Schvaneveldt (1971) observed that participants were almost 100 ms faster to indicate "yes" to pairs of associated words (855 ms, 6.3% errors) than to pairs of non-associated words (940 ms, 8.7% errors). They concluded from this finding that the degree of association was a powerful factor affecting lexical decisions in the yes-no task. They further speculated that the priming could be due either to "spreading of excitation" (as shortly before postulated by Collins & Quillian, 1969) or to a "location shift" (caused by the time needed to shift the readout in memory from one location to another, analogous according to the authors "to how information is retrieved from a tape").

Meta-analyses of associative/semantic priming

The priming effect of associated words has been the topic of hundreds of studies, which have been summarized in two meta-analyses (Lucas, 2000; Van den Bussche, Van den Noortgate, & Reynvoet, 2009).

Lucas (2000) was particularly concerned about the question to what extent the priming effect reported by Meyer & Schvaneveldt is due to the association strength of the words (as measured by association norms) or to their meaning overlap (which she called "true semantic priming"). On the basis of her analysis she concluded that:

1. For associated words, there is a priming effect of d = .5 (this is a medium effect size, which requires 33 participants to have 80% chances of finding a significant two-tailed .05 effect in a repeated measures design).
2. When words are semantically related but not each others' associates according to association norms (as in robin-eagle), there is an effect size of d = .3 (requiring 89 participants to achieve a

power of .80 in a repeated measures design with a two-tailed alpha level of .05). Lucas referred to the difference in effect size between semantically related and semantically + associatively related words as the "associative boost".

3. The true semantic priming effect was smaller for naming (d = .2) than for lexical decision (d = .3).
4. The true semantic priming effect did not depend much on the proportion of related trials vs. unrelated trials.
5. The true semantic priming effect did not depend much on the time between the prime and the target (the so-called stimulus-onset asynchrony, usually abbreviated as SOA).

Lucas (2000) noted that the last two findings related to pure semantic priming seemed to differ from those reported with associative priming, where the effect depends on the SOA (automatic under 250 ms, strategically controlled above) and on the relatedness proportion (with the possibility of negative priming effects in experiments with a low relatedness proportion and a long SOA).

Hutchison (2003) examined the differences between semantic and associative priming reported by Lucas in more detail. Questions he addressed were: Are different processes involved (e.g., feature overlap for semantic priming vs. discourse co-occurrence in associative priming)? Is associative priming only possible for words that also have a meaning overlap? Are there different forms of semantic priming (e.g., feature overlap vs. functional relationships)? On the basis of a microanalysis of the various studies, Hutchison agreed with Lucas that:

1. Automatic semantic priming occurs for functionally related items (as in torch-candle, restaurant-waiter, hammer-nail).
2. There is an associative boost such that semantic pairs sharing an association show larger priming than non-associated pairs (although Hutchison warned that it cannot be excluded

that the boost is due to the associated pairs sharing more semantic features than the non-associated pairs).

Hutchison further disagreed on two aspects with Lucas (2000):

1. There is no strong evidence for automatic priming between different members of a category (i.e., of the type robin-eagle). So, not all types of semantic priming are automatic.
2. There is evidence for pure associative priming between words that are not semantically related.

Van den Bussche, Van den Noortgate, and Reynvoet (2009) expanded the analysis by taking into account not only word primes and targets but all sorts of stimuli (e.g., pictures, Arabic numbers). On the basis of their meta-analysis they added the following factors to the picture:

1. There is a larger effect size (d = .8) in semantic categorization tasks than in lexical decision and naming. Part of this extra effect is due to the fact that automatic stimulus-response connections are formed when the primes and targets come from small categories (e.g., digits, days, months) and are repeatedly presented in the course of the experiment. This is particularly the case when the primes are also used as targets. Part of the priming effect then is due to response congruity. Participants can respond more quickly when the response to the target is the same as that elicited by the prime. Otherwise there is interference of both responses.
2. The semantic priming effect is larger for symbols than for words, both when they are used as primes (d = .9 vs. d = .5) and as targets (d = 1.0 vs. d = .5).
3. In lexical decision and naming there is an average priming effect size of d = .5. The effect is stronger in lexical decision than in naming (no d-values given). For both tasks the priming effect is stronger with large target sets, with large numbers of trials, and with increasing prime duration. There is also some evidence for stronger priming effects in studies with small numbers

of participants than in studies with large numbers of participants, suggesting the presence of a publication bias (because the nonsignificant effects with small samples fail to be reported).

Analysis at the item level

An approach that complements the meta-analyses just mentioned is the study of the item variables that affect the priming effect. Such an analysis was reported by Hutchison, Balota, Cortese, and Watson (2008). They investigated the data of younger adults and older adults on 300-prime target pairs in both lexical decision and naming. They noticed that the priming effect at the item level was reliable enough for analysis (r = .61 or 37% of the variance to explain) when the RTs of the participants were standardized (i.e., for each participant were converted into z-scores on the basis of the mean and the standard deviation of the participant). Otherwise, interindividual differences in overall RT and variability caused too much noise to find any significant predictors. Priming effects were compared for a condition with an SOA of 250 ms (prime presented for 200 ms followed by a blank screen for 50 ms) and a condition with an SOA of 1250 ms (prime presented for 1000 ms followed by a blank screen for 250 ms).

Hutchison et al. (2008) observed first that standardizing the RTs took away the difference in priming between lexical decision (raw priming effect = 56 ms, standardized priming effect = .39) and naming (raw priming effect = 27 ms, standardized priming effect = .35). Apparently lexical decision not only increases the size of the priming effect but also its variability.

Although there were some minor differences between tasks and age groups, the overall findings in the various conditions were remarkably similar. With respect to the prime characteristics, in the SOA=250 ms condition there was more priming for short, frequent primes with few orthographic neighbors. In the SOA=1250 ms condition, priming depended on the speed with which the prime word could be recognized. Surprisingly, this time there was more priming for primes that take long to identify (as assessed by the lexical decision latencies to the prime words in the Elexicon project; Balota et al., 2007). As for the target characteristics, priming was greater for difficult targets with long baseline RTs. Finally, at the short SOA the priming effect depended on the forward association strength between prime and target. This is measured by looking at how many participants in the association norm study report the target as an associate of the prime (e.g., for the prime "nurse", how many participants say "doctor" as the first word they think of). At the long SOA, not only the forward association strength played a role but also the backward association strength (measured by looking at how many participants give the prime as an associate to the target; i.e. for the prime-target pair "nurse-doctor", how many participants say "nurse" when they hear "doctor" in the word associate generation task?).

Masked associative/semantic priming in visual word recognition: a mixed effects analysis

The analyses reported thus far were largely based on primes that were clearly visible (this was not the case for all studies included in Van den Bussche et al., 2009). In recent years, however, the masked priming technique has become the paradigm of preference for many researchers. In this paradigm the prime is presented so briefly that either it cannot be perceived at a conscious level or, when it can be seen, it is not likely to be perceived as an event separate from the target.

To find out to what extent the conclusions mentioned above generalize to masked priming with word primes and targets, we searched the literature for all articles that kept the prime-target SOA at maximally 100 ms and that used lexical decision or naming (there were too few studies about semantic categorization to conclude anything beyond Van den Bussche et al., 2009). We did not observe anything that would contradict the findings of Lucas (2000) and Hutchison (2003) about the associative boost.

Therefore, we dropped this variable, as many studies did not make a clear distinction between semantic overlap and association strength.

We were able to locate 27 articles with a total of 106 priming effects (Appendix A). Although the latter mostly came from different experiments involving different samples of participants, this was not always the case. Sometimes two types of trials were presented within the same experiment or several experiments were run on the same participants. This is indicated in Appendix A by not writing the sample size for conditions based on the same participants as the condition above).

A first problem we were confronted with was that many of the studies did not report enough information to calculate the effect sizes of the various conditions. A typical case is one in which several conditions were examined that did not differ from each other. Then, the authors usually report the overall priming effect without further information about the individual conditions. There are three ways to deal with such situations. The first option (taken by Van den Bussche et al., 2009) is to exclude all studies that do not report the full data. This would reduce the number of conditions in our analysis from 106 to 19. Another option is to estimate the effect sizes on the basis of the partial results reported. A final option is not to work with standardized effect sizes (such as d) but with the raw difference scores mentioned in the articles. Statisticians do not particularly like this score, but in the current case it is perfectly acceptable, as all experiments made use of the same dependent variable (RTs measured in ms) and absolute differences in RTs are thought to be meaningful. As a further precaution, we calculated the correlation between the raw priming effects and the standardized effect sizes for the 19 data pairs we had. This correlation was .71 (n = 19). Furthermore, it was attenuated by an outlier we had spotted before. Chen, Yamouchi, Tamaoka, and Vaid (2007) reported a large priming effect of 34 ms with Japanese Kanji words, which was only marginally significant and resulted in an exceptionally small effect size of r = .19 (see Rastle & Brysbaert, 2006, for the use of r as an index of the effect size). This compares to the mean priming effect of 13 ms overall and the mean effect size of r = .34 (which equals to d = .4). When the Chen et al. (2007) data pair was deleted, the correlation between the raw difference scores and the standardized effect sizes rose to .86. There were no other instances of similarly glaring differences between the priming effect in milliseconds and the associated p-value. Therefore, no other studies from Appendix A were excluded from the analyses below.

To find out which factors influenced the priming effects, we ran correlational analyses and mixed effects models. The latter are a new type of statistical analysis allowing researchers to enter both continuous (linear) and non-continuous variables (e.g., the different languages tested). In addition, these analyses enable one to easily introduce random effects. In the present case we wanted to consider the article in which an effect was published as a random effect, so that effects due to a single article did not contribute excessively to the conclusions. For the rest, the analysis was kept as simple as possible and only served as a powerful eyeball technique. In particular, we did not weight the studies as a function of their sample sizes and we did not make a distinction between effects that were obtained from different samples of participants and effects that were obtained from the same sample. We just wanted to know at a descriptive level the main variables affecting the degree of priming. Appendix A contains the necessary information for colleagues who disagree with the approach taken and want a more in-depth analysis (we are confident that the overall conclusions will not differ in practical terms).

First, we looked at whether there was a correlation between the size of the participant sample and the priming effect reported. As indicated above, a negative correlation would point to a situation in which only significant effects have been published (with larger priming effects required for small sample sizes than for large sample sizes). Figure 1 shows the results of the analysis. The correlation between sample size and priming effect was not significant (r = .126, n = 105) and, if anything, went in the opposite direction (with on average slightly larger effects sizes for studies based on many participants than for studies based on fewer participants).

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Insert Figure 1 about here

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Next we wanted to know whether the priming effect was influenced by the target set size and the number of trials presented in the experiment (many experiments contained more trials than the critical test trials because fillers were introduced and/or the experiment involved several conditions). There was a positive correlation between the target set size and the priming effect ($r = .223$, $n = 105$, $p < .05$), as reported by Van den Bussche et al. (2009). However, there was no such correlation between the number of word trials in the experiment and the priming effect ($r = .042$, $n = 105$). Figure 2 shows the correlation between the number of prime-target pairs used and the size of the priming effect. This picture also illustrates the large scatter that is present when the findings are based on a small number of items.

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Insert Figure 2 about here

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Further correlation checks suggested that the priming effect across studies did not depend on the RT in the unrelated condition ($r = .053$, $n = 105$), but that there was an effect of target repetition ($r = -.226$, $n = 105$, $p < .05$), prime duration ($r = .280$, $n = 105$, $p < .01$), and SOA ($r = .289$, $n = 105$, $p < .01$). The effect of target repetition was due to the fact that in one article (Bueno & Frenck-Mester, 2008) targets were presented twice and in this article rather low priming effects were reported. Such a correlation due to a single source disappears in a mixed model with article as random variable ($F(1,17.8) = 2.94$, $p > .10$).

In the mixed effects model (run on SPSS; see Brysbaert, 2007, for an introduction), we started with a model containing only "source article" as a random variable. This gave us a baseline fit (AIC = 801.2 [1]; Nparameters = 3). Then we entered the continuous variable SOA as the first fixed effect. As could be expected from the correlational analysis, this variable was significant ($F(1,103.0)= 19.01$, $p < .001$; AIC = 788.2, Nparameters = 4). Priming is stronger at long SOAs than at short SOAs. At the shortest durations (around 30 ms) priming is nearly absent. Figure 3 shows the relationship.

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Insert Figure 3 about here

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Next we entered task (LDT vs. naming) as a non-continuous variable. This variable was on the significance borderline ($F(1, 65.6) = 4.14$, $p < .05$; AIC = 780.2, Nparameters = 5) and did not interact with SOA. In numerical terms the mean priming effect of LDT was 17 ms; that of naming was 11 ms (remember from Hutchison et al. (2008), however, that this difference may not survive standardization of the RTs).

Adding language as a non-continuous variable also yielded a significant effect ($F(5,14.8) = 2.85$, $p < .06$; AIC = 742.3, Nparameters = 10). The mean priming effects were 25 ms in Dutch, 22 ms in Chinese, 13 ms in English, 10 ms in Spanish, 6 ms in French, and 2 ms in Arabic. It should be noted, however, that the most extreme values (Dutch, French, Arabic) were based on single source articles. There was also some evidence for an interaction between language and task, but we feel very unsure about interpreting this,

[1] AIC or the Akaike information criterion is a measure indicating goodness of fit of a model. It takes into account both the deviations between observations and predictions and the number of parameters required by the model.

as only three languages had observations in both cells. For Chinese and Spanish, the difference between LDT and naming was substantial (Chinese: 38 vs 13 ms; Spanish: 15 vs. 7 ms); for English it was not (15 vs. 13 ms).

Adding the target set size as a continuous variable to the model did not further improve the fit even though the variable itself came close to significance ($F(1,42.3)=4.34$, $p<.07$; AIC=743.7, Nparameters=11). No further improvements were observed when interaction terms were added. Table 1 summarizes the results of the mixed effects model with source article as a random variable, and SOA, task, and language as fixed effects.

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Insert Table 1 about here

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A final test was run on those studies that examined associative priming and included information about the forward association strength. There were 34 such conditions. For these conditions there was a significant correlation between the priming effect and the association strength ($r = .359$, $n = 34$, $p < .05$), also when SOA was partialled out ($t(31) = 2.93$, $p < .05$). Figure 4 summarizes the relationship. The correlation was attenuated because of 2 outliers with association strength of 66%. These two conditions come from the same source (Balota, Yap, Cortese, & Watson, 2008) and involved one naming task and one lexical decision task (Appendix A). Interestingly, there was no real difference between articles that mentioned the association strength (M = 16 ms) and those that did not (M = 14 ms), arguably because most of the latter used a mixture of associativeness and semantic similarity.

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Insert Figure 4 about here

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In summary, researchers are least likely to find associative/semantic priming in the masked priming paradigm when they use a short SOA, the naming task, and prime-targets with low association strength. Longer SOAs, lexical decision, and strong associations between prime and target increase the size of the priming effect that can be expected. These relationships may not be earth-shattering, but it is good to see them within the wider picture of all the studies run thus far.

Does prime frequency matter?

To our surprise, a variable that has not received much attention in masked associative priming is the frequency of the prime: Is there evidence that at short SOAs a high frequency prime is more efficient than a low frequency prime? Such an effect would be expected on the basis of the most elementary activation model of associative priming according to which the input to the target (based on the prime) depends on the lexical activity of the prime multiplied by the prime-target association strength, i.e.,

$Ti(t) = xp(t) * aPT$

where Ti(t) is the input to the target at time t, xp(t) is the activity of the prime's lexical representation, and aPT is the strength of the association between the prime and the target. In principle, the association can be direct or mediated by conceptual nodes.

This model successfully predicts the effects of the association strength between prime and target (Figure 4): the higher aPT the stronger the input to the target Ti(t). The model also naturally accounts for the rise in priming with longer SOAs (Figure 3). Given that the input to the target (Ti) depends on the activity of the prime (xp) and given that the activity of the prime grows over time (t) until a ceiling level is reached, the model predicts that for short SOAs the priming effect will increase over the period for which the prime is presented. On the basis of Figure 3 we can conjecture that the typical S-shaped activation curve does not reach its plateau before an SOA of 80 ms.

At the same time the model predicts that, if aPT is held constant at some nonzero level, priming should be greater for primes that have a more rapidly growing activation function. If there are two primes, P1 and P2, with $xp1(t) > xp2(t)$ (for $t>0$), then priming effects should be greater for P1 than for P2. The variable most commonly hypothesized to influence the rate of the activation function is prime frequency. So, the simplest model to explain both the effects of association strength and SOA, also predicts that priming effects should be greater for high frequency primes than for low frequency primes, at least as long as the activation levels of P1 and P2 have not reached the ceiling level of their activation curves (i.e., for SOAs below 80 ms).

Some evidence in line with the expected effect of prime frequency can be found in Hutchison et al.'s (2008) analysis, discussed above: Even at an SOA of 250 ms, short, high frequency words primed targets more than long, low frequency words. Or as Hutchison et al. (2008, p. 1053) summarized their findings: "Priming was greater when related primes were short and had few orthographic neighbours. These effects were especially pronounced at the short SOA, where priming was also greater following high-frequency related primes. This pattern makes intuitive sense in that related primes that are quickly identified can exert a greater influence on recognition of the target, especially at short SOAs where quick identification of the prime is critical."

Prime frequency might also account for some unexplained findings in the masked priming literature. For instance, it has been found repeatedly that in bilinguals at short SOAs it is easier to prime targets of the second language with primes from the first language than vice versa (see Schoonbaert, Duyck, Brysbaert,

& Hartsuiker, 2009, for a review). Assuming that bilinguals use their first language more often than their second language, such an effect could simply be a consequence of differences in word frequency. A related observation was made by Brysbaert, Speybroeck, and Vanderelst (2009). They observed that at an SOA of 48 ms it is more difficult to prime target words with acronyms (e.g., BBC-television, ABC-alphabet) than with words of the same length and association strength (ARK-Noah, ELM-tree), whereas equivalent priming was observed at an SOA of 80 ms. Assuming that acronyms are less frequent than words, such a finding could also be explained as the result of differences in activation function due to the prime's frequency.

On the other hand, the prime frequency effect was very small in Hutchison et al. (2008); it was much smaller than the effect of prime length. Also, in the only publication we could find that manipulated prime frequency in a masked priming experiment, a null effect was reported. Lukatela and Turvey (1994) made a distinction between associative primes of high and low frequency and had to hide this manipulation behind the significant effect of homophony because it failed to reach significance (participants had to name the targets). So, the evidence for an effect of prime frequency in masked associative priming is sketchy at best.

To examine the issue properly, we decided to run two new studies: one with an SOA of 250 ms and one with SOAs below 100 ms (i.e., masked priming). The primes differed in frequency and were matched as well as possible on a series of other variables (length, forward association strength, backward association strength, LSA and orthographic overlap with the target). Similarly the targets of both types of primes were matched. Finally, enough stimuli and participants were used to make sure that any frequency effect would come out if it was there (assuming we were dealing with a small effect). First, we discuss the condition with SOA = 250 ms, the short condition used by Hutchison et al.'s (2008).

Experiment 1

In this experiment, target words were preceded by primes with a high association strength (>50%). Primes differed in frequency to find out whether high-frequency words have a stronger priming effect than low-frequency words at an SOA of 250 ms.

Method

Participants. Thirty students from Royal Holloway, University of London took part in the experiment. They all had normal or corrected to normal vision and were unaware of the research hypothesis. They were paid for their participation, had given informed consent, and were informed that they could withdraw from the experiment at any moment without cost.

Stimuli. The word stimuli consisted of 180 targets with related and unrelated primes (Appendix B). Half of the pairs had low frequency primes (4 per million according to the British National Corpus database; Leech, Rayson, & Wilson, 2001; available online at http://ucrel.lancs.ac.uk/bncfreq/), half had high frequency primes (148 per million). As shown in Table 2, the stimuli were matched on important factors, such as length and semantic overlap with the target as measured with the LSA coefficient (Latent Semantic Analysis; Landauer & Dumais, 1997; online available at http://lsa.colorado.edu/). The items were also controlled for the forward association strength between the primes and the targets according to the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 2004; available online at http://w3.usf.edu/FreeAssociation/) and the backward association strength from the target to the primes (also based on the University of South Florida Free Association Norms). The forward association strength (FAS) was as high as possible (range: .40 -.83); the backward association strength (BAS) was rather low (range: .00 - .39). Finally, the stimuli were matched on the orthographic similarity between the primes and the targets (calculated according to the equation given in Van Orden, 1987).

The only factor we could not fully control was the orthographic neighborhood of the primes, as calculated with N-Watch (Davis, 2005). The high-frequency primes had significantly less neighbors than the low frequency primes and the related primes had significantly less neighbors than the unrelated primes. According to Hutchison et al. (2008) this could favor the high frequency primes (as they are less confusable with other words).

Two stimulus lists were made according to a split-plot design, so that participants saw half of the targets with the related primes and half with the unrelated primes but that across participants each target was seen by half of the participants with a related prime and by half with an unrelated prime.

Next to the word stimuli, we made 180 nonword stimuli. These stimuli were compiled in the same way as the word stimuli (i.e., they consisted of 180 target words with highly associated primes and matched unrelated primes). Then, the target words were turned into legal nonwords by changing one or two letters.

Procedure. Stimulus presentation was controlled with DMDX (Forster & Forster, 2003). Before the test session of 360 trials, participants completed a practice session of 10 trials. On each trial, a fixation symbol (+) was presented for 200 ms, followed by a forward mask (######) for 500 ms, the prime word for 250 ms, and the target word, which remained visible until the participant made a response or 2000 ms had elapsed. Participants responded with the dominant hand to the word stimuli (for all but one participant the right hand) and with the nondominant hand to the nonword stimuli.

Results

Response times longer than 1500 ms were discarded (0.1%). No other data trimming occurred. Table 3 shows the data. There was no evidence for a speed-accuracy trade-off. Therefore the low error rates were not analyzed separately.

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Insert Table 3 about here

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With respect to the response latencies, there was a significant priming effect for the low frequency primes ($F1(1,29) = 62.11$, $MSe = 212.0$, $p < .01$, $d = 1.4$, $r = .83$; $F2(1,88) = 29.56$, $MSe = 1008$, $p < .01$, $d = .8$, $r = .50$) and for the high frequency primes ($F1(1,29) = 21.71$, $MSe = 437$, $p < .01$, $d = .9$, $r = .65$; $F2(1,88) = 36.20$, $MSe = 1145$, $p < .01$, $d = .8$, $r = .54$). Importantly, there was no hint of an interaction ($F1(1,29) = .64$, $MSE = 234.6$; $F2(1,176) = .33$, $MSe = 176$) nor a main effect due to prime frequency ($F1(1,29) = 2.76$, $MSe = 400.0$; $F2(1,176) = 1.30$, $MSe = 2030$).

To examine the variables contributing to the priming effect, we calculated the z-scores of the participants (Hutchison et al., 2008) and established the priming effect for each stimulus by subtracting the z-score of the related condition from the z-score of the unrelated condition. We failed to find any significant predictor of these difference scores, possibly because the participant groups were too small (twice 15). Another reason may be the restricted range used for several variables as part of our matching for potentially confounding variables (e.g., frequency of the target, forward and backward association strengths between prime and target, length of the prime).

Discussion

The priming effects of 25-30 ms, observed in Experiment 1, fit well within the pattern shown in Figure 3 (associative/semantic priming as a function of SOA). There was no evidence that the frequency of the prime made a difference for the degree of priming, contrary to the suggestion made by Hutchison et al.

(2008; see above). This may be because the frequency of the prime has no impact, or because both low-frequency and high-frequency words have reached their maximal activation levels at SOA=250 ms. Indeed, eye fixation times in normal reading typically are of the order of 250 ms and at a reading speed of 300 words per minute (the speed one would expect for good university students) people recognize 5 words per minute (admittedly including easy function words such as the articles before the nouns). So, it is possible that an SOA of 250 ms is too long to see a clear effect due to the frequency of the prime. Experiment 2 examined whether the word frequency effect would become stronger at shorter SOAs.

Experiment 2

In Experiment 1 we failed to find a prime frequency effect with SOA = 250 ms. In the present experiment we looked at SOAs below 100 ms. More specifically we investigated the associative/semantic priming at SOAs of 34, 57, and 80 ms, which are in the time range in which the priming effect starts to emerge (Figure 3)

Method

Participants. Forty-two students from Royal Holloway, University of London took part in the experiment. One participant had to be excluded because they made too many errors. All participants had normal or corrected to normal vision and were unaware of the research hypothesis. They were paid for their participation, had given informed consent, and were informed that they could withdraw from the experiment at any moment without cost.

Stimuli. The stimuli were the same as in Experiment 1. However, because the present experiment contained 12 conditions (low frequency/high frequency * 3 SOA levels * related/unrelated), the number of observations per cell was limited to 15. To present all stimuli in equal numbers in each of the 6 SOA * relatedness conditions, 6 stimulus lists were made according to a Latin-square design. Each list except for one was seen by 7 participants.

Procedure. The procedure was the same as in Experiment 1.

Results

Two RTs longer than 1500 ms were omitted (making less than .1%). Table 4 shows the priming effects as a function of prime frequency and SOA. As the percentage of errors was low and there was no evidence for a speed-accuracy trade-off, no ANOVAs were run on the PE.

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Insert Table 4 about here

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Analyses of variance were run on the RTs with the variables Prime Frequency (2 levels), SOA (3 levels), and Prime Relatedness. These yielded a significant main effect of Prime relatedness ($F1(1,40) = 5.88$, $MSe = 1649$, $p < .03$, $r = .36$; $F2(1,178) = 7.67$, $MSe = 3228$, $p < .01$, $r = .20$) and a close to significant main effect of SOA ($F1(2,80) = 3.34$, $MSe = 947$, $p < .05$; $F2(2,356) = 2.34$, $MSe = 2827$, $p < .10$). The main effect of Prime Frequency was nearly significant in F1 ($F1(1,40) = 4.00$, $MSe = 1034$, $p < .06$) but not in F2 ($F2(1,178) = 1.42$, $MSe = 7271$). Neither the interaction between Prime Relatedness and Prime Frequency ($F1(1,40) = .61$, $MSe = 152$; $F2(1,178) = .69$, $MSe = 3228$) nor the interaction between Prime Relatedness and SOA ($F1(2,80) = .38$, $MSe = 1280$; $F2(2,356) = .51$, $MSe = 2205$) reached significance, although a look at Table 4 indicates that the priming effect grows with SOA, also in terms of standardized effect sizes (34 ms: d1 = .17, d2 = .09; 57 ms: d1 = .22, d2 = .14; 79 ms: d1 = .32, d2 = .18).

As in Experiment 1, we failed to find significant predictors of the priming effects at the item level (expressed in z-scores).

To have a better idea of the similarities and the differences between Experiment 1 and 2, we ran an additional mixed effects analysis with participants and prime-target combination as random effects, and SOA, forward association strength (FSG), orthographic overlap between prime and target, log frequency of the prime and the target, and the length of the target as fixed effects (Baayen, 2008). Dependent variable was lexical decision time to the target word; p-values were based on MCMC sampling. This analysis revealed faster responses to high frequency targets (regression weight (B) = -12.4, t = -8.68, p < .01), short target words (B = 4.8, t = 4.30, p < .01), short SOAs (B = .15, t = 3.12, p < .01), a high orthographic similarity between prime and target (B = .056, t = -3.28, p < .01), and a low prime frequency (B = 4.01, t = 3.26, p < .01). Surprisingly, there was no main effect of forward association strength (B = -7.07, t = -.91, p = .36), but there was a significant interaction between FSG and SOA (B = -.16, t = -3.94, p < .01). The latter was due to the fact that the effect of FSG grew stronger with increasing SOA (i.e., it was strongest for SOA = 250 ms and weakest for SOA = 34 ms). There were also significant interactions between SOA and log prime frequency (B = -.02, t = -3.31, p < .01) and between SOA and orthographic similarity between prime and target (B = .0002, t = 2.79, p < .01). These were due to the fact that the effects of prime frequency and orthographic similarity were limited to the masked priming conditions. They were not present in Experiment 1 (SOA = 250 ms). Similar (but less pronounced) results were obtained when FSG was replaced by LSA.

Discussion

As in Experiment 1, the priming effects observed fitted well within the general pattern of priming effects reported in the literature (Figure 3). At SOA = 34 ms priming was almost absent (5.5 ms); at SOA = 57 ms there was a priming effect of 9.5 ms, which grew to 12.5 ms for SOA = 79 ms. Although the latter tends toward the low end (certainly for the high frequency primes, given the values we obtained in the other conditions and in Experiment 1), it is within the range of effects reported at this SOA (Figure 3).

Again, however, we failed to obtain any evidence for stronger priming with high-frequency words than with low-frequency words. As in Experiment 1, the effect tended to be in the opposite direction, suggesting that despite our efforts to match the two prime lists, the list with high-frequency primes contained a few less good items (on the basis of the available evidence, we do not want to postulate an *inverse* frequency effect).

General discussion

The present studies were designed to find out whether the frequency of the prime is an important variable in masked associative/semantic priming studies. Such an effect would be in line with a simple model that sees associative priming as the outcome of activation input from the prime's lexical representation to the target's lexical representation, with the activation build-up depending on (i) the association strength between the prime and the target and (ii) on the activity level of the prime's lexical representation. Such an effect would further be in line with Hutchison et al.'s (2008) finding that short, frequent words with few orthographic neighbors induce the strongest priming effects. Finally, it would also provide an explanation why it is difficult to find priming with low frequency stimuli (words in L2, acronyms) at very short SOAs.

Against the above lines of reasoning, however, we failed to find any support for a difference in priming between words with an average frequency of 4 per million and words with an average frequency of more than 120 per million. This was true both for an SOA of 250 ms (Experiment 1) and SOAs below 100 ms (Experiment 2). In particular the latter is surprising given that the activation function is increasing faster for high-frequency than for low-frequency words. According to the Elexicon project (Balota et al., 2007) the low-frequency primes we used take about 50 ms longer to be recognized in a lexical decision task than the high-frequency primes (675 ms vs. 626 ms). Still, if anything, they induced slightly more priming, even in the masked priming conditions of Experiment 2. Previously, Lukatela and Turvey (1994) had also failed to obtain a difference in associative priming between high and low-frequency primes, and the empirical evidence for a specific contribution of word frequency in Hutchison et al. (2008) was rather weak (only the effect on error rate in the long SOA condition with lexical decision was significant; see tables 4 and 5 of their article). Together these findings make it quite unlikely that prime frequency could influence the degree of associative priming either at long or at short SOAs. Instead, it seems there is more need to try to understand why frequency fails to have an impact.

To get a better insight, we decided to have a closer look at the performance of a computational model that has been proposed for semantic and associative priming (Plaut, 1995; Plaut & Booth, 2000). In this distributed connectionist model artificial orthographic inputs make contact to a layer of semantic units through a layer of hidden units. Semantic similarity of the input words is introduced by grouping the words into 8 semantic categories; words of the same category have overlapping semantic representations. Associative priming is simulated by manipulating the probability of a word being followed by a word of the same category: Chances that a word from the same category follows the prime word are twice as high as those of an unrelated word following the prime. In other words, the "associative boost" (Lucas, 2000) in the model is caused by the transition probabilities in the training phase.

Plaut (1995) and Plaut and Booth (2000) showed that their model is capable of simulating many patterns of human data. For instance, the model simulated the larger priming effect for low-frequency targets than for high-frequency targets, and the fact that this effect interacted with the perceptual ability of the participants (it was particularly present for the high-ability group). Unfortunately, neither Plaut (1995) nor Plaut and Booth (2000) discussed the impact of prime frequency in their model.

When contacted, Plaut (personal communication, June 12, 2009) kindly provided us with the outcome of the model as a function of prime frequency and SOA. These data are shown in Figure 5. The SOA of the model was set so that it equaled 50 ms, 100 ms, 200 ms, or 800 ms. Although there was some more priming for high-frequency primes than for low-frequency primes, ANOVAs over stimuli indicated that the difference did not reach significance until at the longest SOA (800 ms). Another interesting result was that the difference between high and low-frequency primes grew bigger with longer SOAs, in contrast with our intuition that high-frequency primes would have a particular advantage at short SOAs given that they are more efficient at activating their meaning.

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Insert Figure 5 about here

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The observation that high-frequency primes do not result in significantly more priming in Plaut's model seems to be the outcome of two variables. First, the activation of semantic features takes quite some time, which explains why the difference between high and low-frequency primes increases with longer

SOAs. The second reason has to do with the co-occurrences of high-and low-frequency words (remember that in Plaut's model associative priming is operationalized as the transition probability between prime and target). On average, we can expect that the relative chances of a low-frequency prime being followed by its target are higher than the relative chances of a high-frequency prime being followed by its target. Take, for instance, the two primes "surgeon" and "doctor" and the target "hospital". The first prime is much less common than the second (16 per million words vs. 264 per million words; Brysbaert & New, in press). However, when it occurs, it is likely to be followed shortly afterwards by the word "hospital". In contrast, because "doctor" is a high-frequency word it is encountered in many more contexts than those related to "hospital". Such a difference in relative probabilities could explain why low-frequency primes are better than high-frequency primes to activate their target. This is particularly the case when the frequencies of the targets are matched for the high-frequency and the low-frequency primes, as happened in our study (in unselected, real-life materials it is not unreasonable to assume a positive correlation between the frequencies of primes and targets).

It might be objected that our selection of stimuli prevented such a bias from happening. After all, the high- and low-frequency primes were matched on LSA and on forward and backward association strength. However, on further scrutiny this matching may not have been strict enough. The LSA measure, for instance, estimates the chances of two words occurring in similar contexts, not of the target *following* the prime. In addition, this measure is known to be affected by the frequencies of the words involved in the comparison (Shaoul & Westbury, 2006).

To have a better estimate of the chances of our primes being followed by their target, we contacted Shaoul, who kindly provided us the HiDEx (High Dimensional Explorer) probabilities of each prime being immediately followed by its target (personal communication, August 7, 2009). As predicted, the probability of the related low-frequency primes preceding their targets (.76%) was higher than the probability of the related high-frequency primes preceding their targets (.10%; the probabilities of the unrelated primes preceding the targets were .01% for the low-frequency primes and .003% for the high-frequency primes). This resulted in a next to significant interaction between Prime Frequency and Prime Relatedness ($F(,1,178) = 5.43$, $MSe = 2.95$, $p < .08$).[2]

The idea of differences in transition probabilities as the mechanism underlying associative priming can also be implemented in a localist connectionist model. Assuming that all connections between activated words and active concept nodes become stronger under the influence of Hebbian learning, one can expect that high-frequency primes (which occur in many different contexts) will become connected to many more conceptual nodes than low-frequency primes. Further assuming a process of lateral inhibition between competing concept nodes or a normalization of the word output weights, it follows that the word nodes connected to a small number of concept nodes will be more efficient in activating the nodes than words connected to a large number of concept nodes.

In summary, although the null-effect of prime frequency at different SOAs was quite surprising to us at first sight, it does not seem to be at odds with the dynamics of computational models and it constrains the dynamics of these models in interesting ways. In addition, finding that prime frequency does not make a difference in masked associative/semantic priming has practical implications as well. In particular, it means that differences in word use cannot be invoked to explain systematic differences in priming effects between various types of stimuli. For instance, Van den Bussche et al. (2009) noticed that larger priming effects were observed with nonverbal stimuli than with verbal stimuli. Similarly, it has been reported repeatedly that it is more difficult to prime targets from the first language with semantically related words from a second language than the other way around (Schoonbaert et al.,

[2] It might be objected that the absolute frequencies are too low to have any practical impact. However, these are the probabilities of the primes being followed immediately by their targets. If a wider window of a few intermediate words is used, the absolute values can be expected to increase substantially.

2009). Although it is tempting to attribute these differences in priming capacity to variations in the amount of experience with the various stimulus types, the present data (together with those of Lukatela & Turvey, 1994) strongly suggest that the frequency with which stimuli are encountered is of little importance in associative priming at short SOAs. It seems more worthwhile to look for other factors to explain these empirical findings.

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Table 1 : Significant variables in the mixed effects analysis of the studies listed in Appendix A. Task = naming vs. lexical decision.

Type III Tests of Fixed Effects(a)

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	71,152	,366	,547
Task	1	42,702	7,931	,007
SOA	1	96,192	20,713	,000
language	5	14,761	2,851	,053

a Dependent Variable: Prim.

Table 2 : Characteristics of the stimuli used in Experiments 1 and 2. BNC = British National Corpus, LSA = latent semantic analysis, FAS = forward association strength, BAS = backward association strength, Orth-sim : orthographic similarity.

	Low frequency primes			High frequency primes		
	Rel.	Unrel.	Target	Rel.	Unrel.	Target
Frequency (BNC)	4.0	4.0	123.2	124.1	124.1	172.3
Length (letters)	5.5	5.5	4.8	6.0	6.0	4.8
N	4.3	4.7	6.3	2.8	3.9	5.6
$LSA_{prime-target}$	.44	.04		.47	.09	
$FAS_{prime-target}$	.55	.00		.52	.00	
$BAS_{prime-target}$	.09	.00		.12	.00	
$Orth\text{-}sim_{prime-target}$	124	125		129	122	

Table 3: Results from Experiment 1 (SOA = 250 ms). Between brackets: the standard deviation of the priming effect across items.

	Low frequency prime		High frequency prime	
	RT	PE	RT	PE
Related	508	.01	504	.02
Unrelated	538	.03	529	.03
Priming effect	30 (60.7)		25 (61.1)	

Table 4: Results from Experiment 2 (SOA < 100 ms). Between brackets: the standard deviation of the priming effect across items.

SOA = 34 ms

	Low frequency prime		High frequency prime	
	RT	PE	RT	PE
Related	524	.02	538	.05
Unrelated	529	.04	544	.04
Priming effect	5 (71.9)		6 (62.6)	

SOA = 57 ms

	Low frequency prime		High frequency prime	
	RT	PE	RT	PE
Related	531	.02	534	.04
Unrelated	540	.05	544	.03
Priming effect	9 (72.7)		10 (76.3)	

SOA = 79 ms

	Low frequency prime		High frequency prime	
	RT	PE	RT	PE
Related	518	.02	526	.01
Unrelated	539	.04	530	.04
Priming effect	21 (71.8)		4 (74.1)	

Figure 1 : The lack of a relationship between the size of the priming effect and the size of the participant sample. This suggests that there has not been a publication bias only to report significant effects.

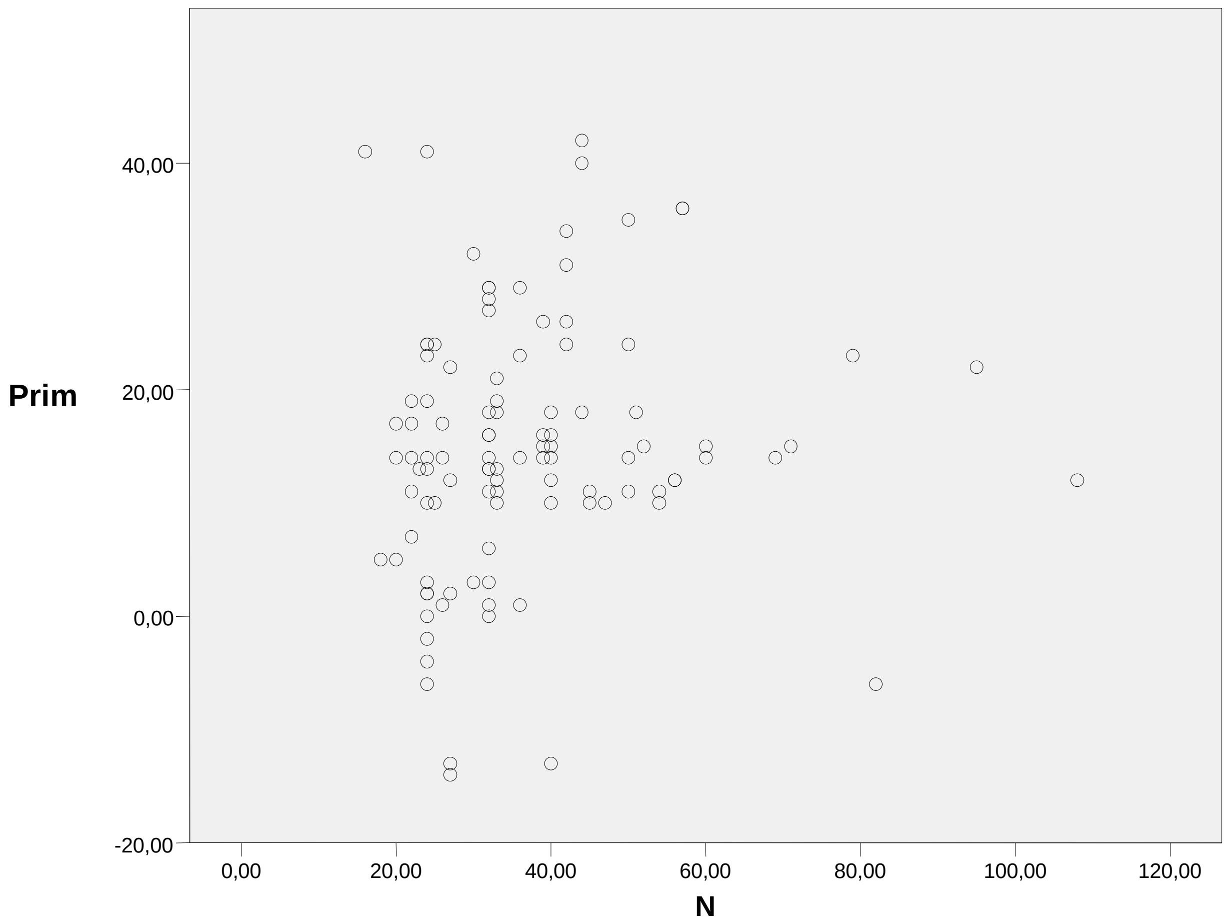


Figure 2: Relationship between the prime size and the number of stimuli used in the experiment. Notice the negative priming effects for small stimulus samples.

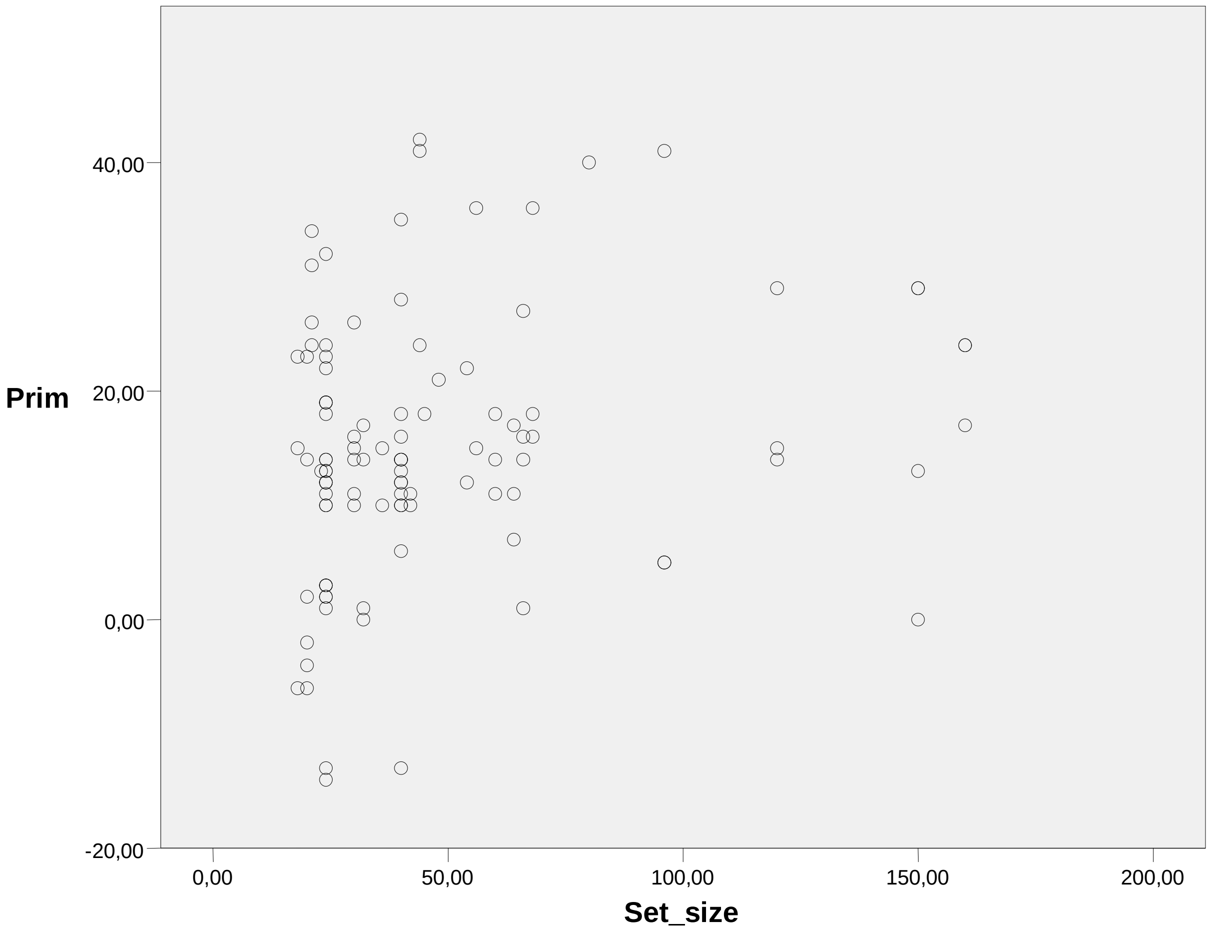


Figure 3: Relationship between SOA and the priming effect. At the shortest SOA (30 ms) the priming effect is close to 0; at the longest SOAs (80-100 ms) it is around 20 ms.

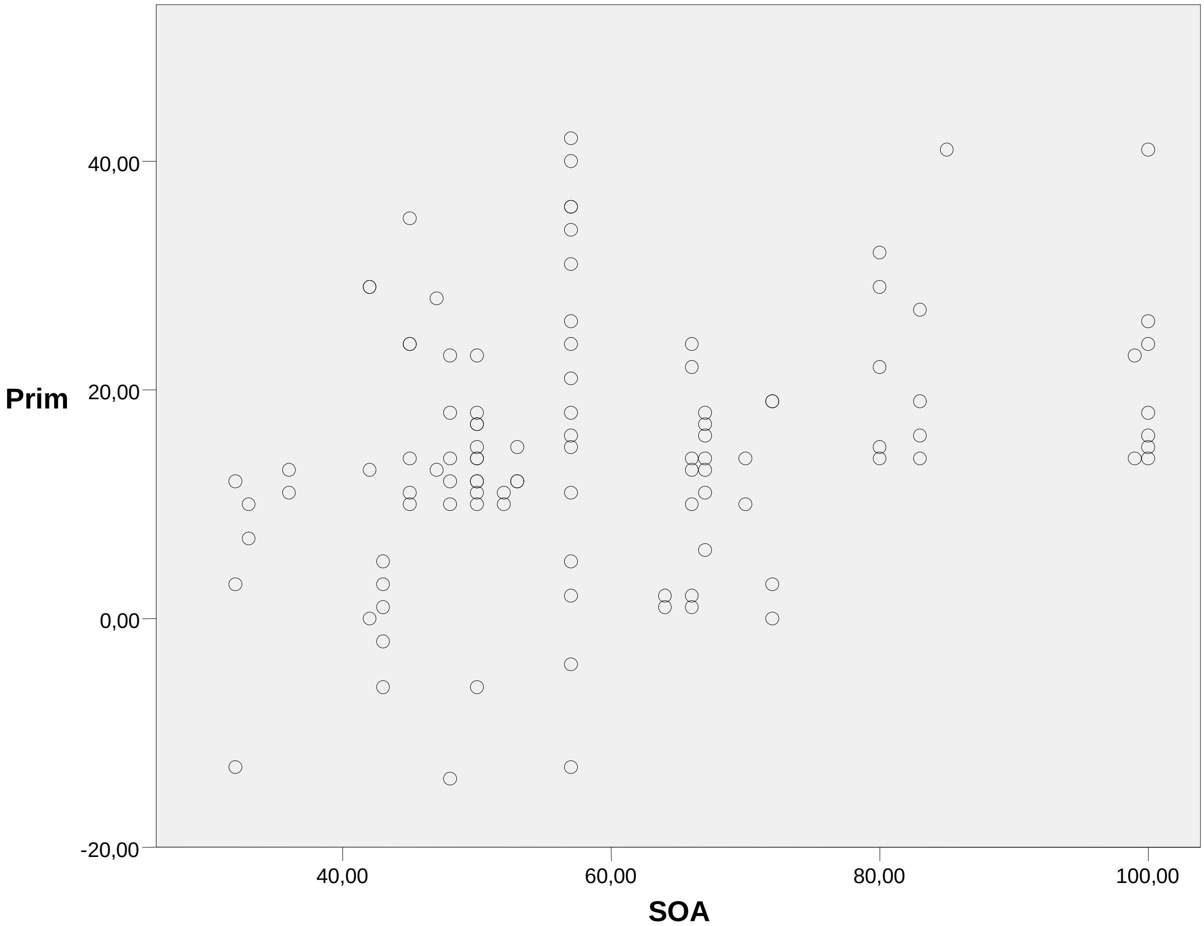


Figure 4: Relationship between the prime-target association strength and the priming effect. In general the effect is positive. The two outliers at Assoc = 66% come from a single study.

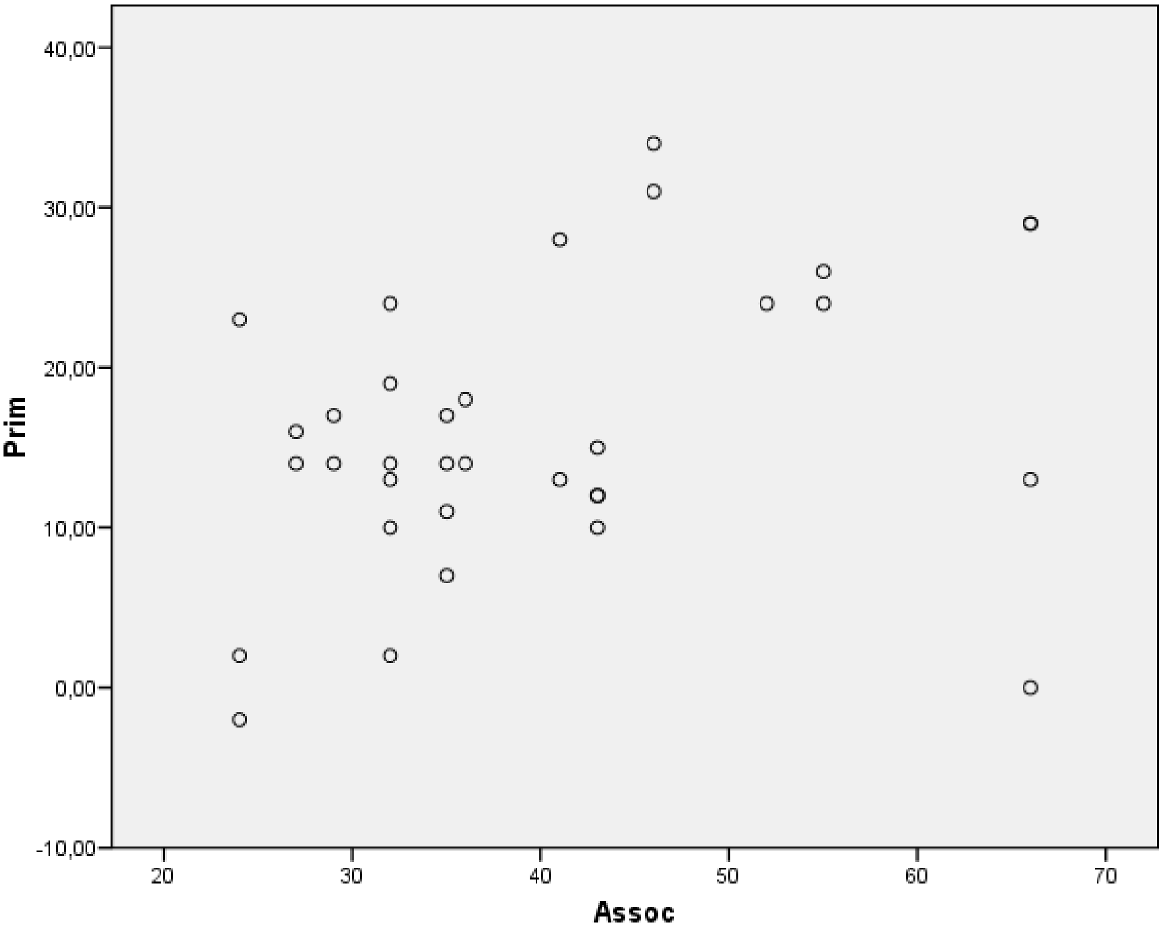
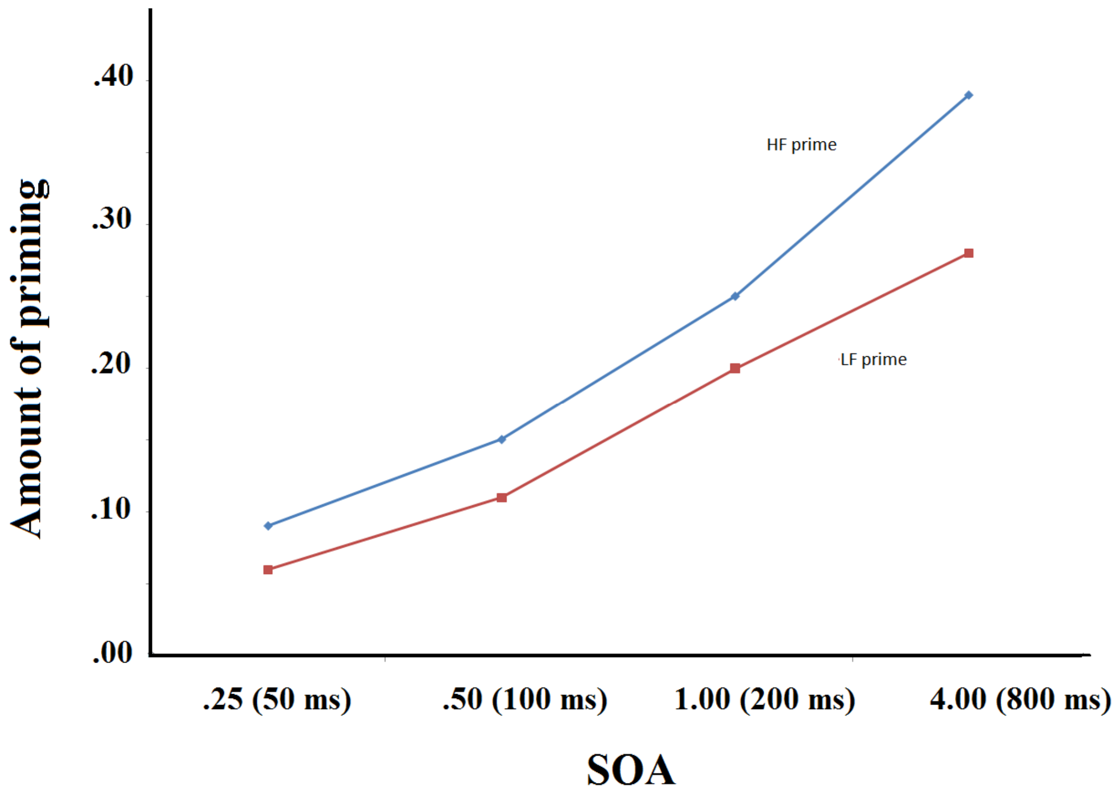


Figure 5 : Priming effects for low- and high-frequency primes in Plaut's (1995) computational model of semantic and associative priming as a function of SOA. Only at SOA = 800 ms does the difference between high- and low-frequency primes reach significance.



Appendix A: Studies used in the mixed effects analysis

Study	Exp.	Relationship	N	Task	Set size	Targ rep.	Word Trials	Prime dur.	SOA	FREQprim	FREQtar	Rtrel	Rtunrl	Prim	PErel	PEunrl	language
Balota et al. (2008)	7	associative (66%)	32	lexical decision	150	1	300	42	42	8.56	4.83	562	575	13	4.1	5.4	English
Balota et al. (2008)		associative (66%)	32	lexical decision	150	1	300	42	42	8.56	4.83	686	715	29	7.3	8.7	English
Bodner & Masson (2003)	1a	associative	50	lexical decision	40	1	200	45	45	?	34	653	667	14			English
Bodner & Masson (2003)	1a	associative	50	lexical decision	160	1	200	45	45	?	34	655	679	24			English
Bodner & Masson (2003)	1b	associative	25	lexical decision	40	1	200	45	45	?	34	626	636	10			English
Bodner & Masson (2003)	1b	associative	25	lexical decision	160	1	200	45	45	?	34	611	635	24			English
Bodner & Masson (2003)	2	associative	50	lexical decision	40	1	200	45	45	?	34	700	711	11			English
Bodner & Masson (2003)	2	associative	50	lexical decision	40	1	200	45	45	?	34	640	675	35			English
Boudelaa & Marslen-Wilson (2005)	1	semantic relatedness	32	lexical decision	24	1	144	32	32	?	?	633	636	3	6	6	Arabic
Boudelaa & Marslen-Wilson (2005)	1	semantic relatedness	40	lexical decision	24	1	144	48	48	?	?	639	651	12	4.6	7.6	Arabic
Boudelaa & Marslen-Wilson (2005)	1	semantic relatedness	36	lexical decision	24	1	144	64	64	?	?	628	629	1	7	7	Arabic
Boudelaa & Marslen-Wilson (2005)	1	semantic relatedness	30	lexical decision	24	1	144	80	80	?	?	578	610	32	7.2	5.3	Arabic
Boudelaa & Marslen-Wilson (2005)	2	semantic relatedness	27	lexical decision	24	1	144	32	32	?	?	631	618	-13	6.7	5.3	Arabic
Boudelaa & Marslen-Wilson (2005)	2	semantic relatedness	27	lexical decision	24	1	144	48	48	?	?	631	617	-14	8.7	5.4	Arabic
Boudelaa & Marslen-Wilson (2005)	2	semantic relatedness	27	lexical decision	24	1	144	64	64	?	?	614	616	2	6.9	5.2	Arabic
Boudelaa & Marslen-Wilson (2005)	2	semantic relatedness	27	lexical decision	24	1	144	80	80	?	?	564	586	22	8.1	5.7	Arabic
Bueno & Frenck-Mestre (2008)	5a	feature overlap	24	lexical decision	20	2	60	28	43	16.4	10.3	607	601	-6	8.5	10	French
Bueno & Frenck-Mestre (2008)	5b	Associative (24%)		lexical decision	20	2	60	28	43	45.1	121.9	543	541	-2	1.4	0.6	French
Bueno & Frenck-Mestre (2008)	5c	feature overlap	24	lexical decision	20	2	60	43	57	16.4	10.3	608	604	-4	9.2	8	French
Bueno & Frenck-Mestre (2008)	5d	Associative (24%)		lexical decision	20	2	60	43	57	45.1	121.9	548	550	2	1.2	1.6	French
Bueno & Frenck-Mestre (2008)	6a	feature overlap	24	lexical decision	20	2	60	71	99	16.4	10.3	646	660	14	8.5	8.5	French
Bueno & Frenck-Mestre (2008)	6b	Associative (24%)		lexical decision	20	2	60	71	99	45.1	121.9	581	604	23	1.5	3	French
Chen et al. (2007) *	1	semantic	24	lexical decision	72	1	96	85	85	13	16	741	775	34	7.3	10.8	Japanese
Drieghe & Brysbaert (2002)	2a	Associative (54.8%)	42	lexical decision	21	1	42	57	57	?	?	565	589	24	3.4	5	Dutch
Drieghe & Brysbaert (2002)	2b	Associative (46.1%)		lexical decision	21	1	42	57	57	?	?	571	605	34	1.7	3.4	Dutch
Drieghe & Brysbaert (2002)	4a	Associative (54.8%)	42	lexical decision	21	1	42	57	57	?	?	576	602	26	1.4	2.3	Dutch
Drieghe & Brysbaert (2002)	4b	Associative (46.1%)		lexical decision	21	1	42	57	57	?	?	569	600	31	1.4	1.7	Dutch
Dunabeitia et al. (2008)	1	Associative (36%)	69	lexical decision	60	1	60	50	50	19.3	51.7	672	686	14	3.3	3	Spanish
Dunabeitia et al. (2008)	3	Associative (36%)	51	lexical decision	60	1	140	50	50	19.3	51.7	658	676	18	4.2	4.2	Spanish
Estes & Jones (2009)	2	semantic (2%)	44	lexical decision	45	1	45	100	100	?	?	613	631	18	1	1	English
Feldman (2000)	1a	semantic	95	lexical decision	54	1	72	16	66	34	108	592	614	22	11	13	English
Feldman (2000)	1b	semantic	108	lexical decision	54	1	72	32	32	34	108	641	653	12	12	14	English
Feldman & Basnight-Brown (2008)	1	Semantic relatedness	82	lexical decision	18	1	108	50	50	33.6	107	664	658	-6			English
Feldman & Basnight-Brown (2008)	2	Semantic relatedness	79	lexical decision	18	1	108	50	50	33.6	107	649	672	23			English
Feldman & Basnight-Brown (2008)	3	Semantic relatedness	71	lexical decision	18	1	108	50	50	33.6	107	667	682	15			English
Ferrand & New (2003)	1a	semantic (5%)	24	lexical decision	44	1	88	100	100	?	16	562	603	41	0.9	2	French
Ferrand & New (2003)	1b	associative (52%)		lexical decision	44	1	88	100	100	?	98	537	561	24	1.2	0.6	French
Grossi (2006)	1a	Associative (29%)	20	lexical decision	160	1	200	50	50	105	123	558	575	17	5.1	7.7	English
Grossi (2006)	1a	Associative (29%)	20	lexical decision	40	1	200	50	50	105	123	569	584	14	4.7	5.6	English
Marslen-Wilson et al. (2008)	1a	Semantic relatedness (moderat	33	lexical decision	24	1	216	36	36	5.5	10.5	527	538	11	11	11	English
Marslen-Wilson et al. (2008)	1a	Semantic relatedness (strong)		lexical decision	24	1	216	36	36	7.9	14.2	517	530	13	6	6	English
Marslen-Wilson et al. (2008)	1b	Semantic relatedness (moderat	33	lexical decision	24	1	216	48	48	5.5	10.5	532	542	10	8	9	English
Marslen-Wilson et al. (2008)	1b	Semantic relatedness (strong)		lexical decision	24	1	216	48	48	7.9	14.2	523	541	18	6	7	English
Marslen-Wilson et al. (2008)	1c	Semantic relatedness (moderat	30	lexical decision	24	1	216	72	72	5.5	10.5	564	567	3	8	10	English
Marslen-Wilson et al. (2008)	1c	Semantic relatedness (strong)		lexical decision	24	1	216	72	72	7.9	14.2	537	556	19	3	9	English
Marslen-Wilson et al. (2008)	2	Semantic relatedness (moderat	36	lexical decision	24	1	216	48	48	10.5	5.5	582	595	14	7	6.7	English
Marslen-Wilson et al. (2008)	2	Semantic relatedness (strong)		lexical decision	24	1	216	48	48	14.2	7.9	581	604	23	6.5	6.9	English

Perea & Gotor (1997)	1a	Associative (35%)	22	lexical decision	64	1	64	33	33	?	?	677	684	7	1.8	2.5	Spanish
Perea & Gotor (1997)	1b	Associative (35%)	22	lexical decision	64	1	64	50	50	?	?	683	700	17	0.9	3.2	Spanish
Perea & Gotor (1997)	1c	Associative (35%)	22	lexical decision	64	1	64	67	67	?	?	675	686	11	1.6	2.3	Spanish
Perea & Gotor (1997)	3a	Associative (35%)	26	lexical decision	32	1	64	67	67	?	?	651	665	14	0.5	2.4	Spanish
Perea & Gotor (1997)	3b	Semantic relatedness		lexical decision	32	1	64	67	67	?	?	710	727	17	3.2	4.7	Spanish
Perea et al. (1997)	1a	Semantic relatedness	32	lexical decision	40	1	120	67	67	?	?	710	704	6	5.6	5.2	Spanish
Perea et al. (1997)	1b	Associative (?)		lexical decision	40	1	120	67	67	?	?	683	667	16	2.7	2.3	Spanish
Perea et al. (1997)	1c	Associative (?)		lexical decision	40	1	120	67	67	?	?	683	665	18	2.7	1.3	Spanish
Perea & Rosa (2002)	1a	Associative (27%)	32	lexical decision	66	1	66	66	66	78	87	739	753	14	2.9	4.3	Spanish
Perea & Rosa (2002)	1b	Associative (27%)	32	lexical decision	66	1	66	83	83	78	87	718	734	16	1.8	2.6	Spanish
Perea & Rosa (2002)	2a	Semantic relatedness	32	lexical decision	66	1	66	66	66	84	25	764	765	1	6.4	8	Spanish
Perea & Rosa (2002)	2b	Semantic relatedness	32	lexical decision	66	1	66	83	83	84	25	778	805	27	5.3	7	Spanish
Perea & Rosa (2002b)	2a	Asscoiative strength (32%)	24	lexical decision	24	1	66	66	66	?	?	682	692	10	5.4	5.4	Spanish
Perea & Rosa (2002b)	2b	Asscoiative strength (32%)	24	lexical decision	24	1	66	66	66	?	?	691	715	24	4.1	4.8	Spanish
Perea & Rosa (2002b)	5a	Asscoiative strength (32%)	22	lexical decision	24	1	66	83	83	?	?	699	718	19	1.5	3.8	Spanish
Perea & Rosa (2002b)	5b	Asscoiative strength (32%)	22	lexical decision	24	1	66	83	83	?	?	690	704	14	3.1	5.7	Spanish
Perea & Lupker (2003)	1a	Associative	60	lexical decision	120	1	120	40	80	?	105	633	647	14	1.5	2.1	English
Perea & Lupker (2003)	1b	Associative	60	lexical decision	120	1	120	40	80	?	105	686	701	15	2	3.3	English
Perea & Lupker (2003)	2	Associative	36	lexical decision	120	1	120	40	80	?	105	556	585	29	3.9	6.1	English
Perea et al. (2008)	2	Associative (41%)	32	lexical decision	40	1	40	47	47	82	153	628	641	13	1.6	2.8	Spanish
Perea et al. (2008)	3	Associative (41%)	32	lexical decision	40	1	40	47	47	82	153	693	721	28	0.9	0.6	Spanish
Rastle et al. (2000)	1a	semantic relatedness	24	lexical decision	24	1	180	43	43	?	31	602	605	3	4	2.9	English
Rastle et al. (2000)	1b	semantic relatedness	24	lexical decision	24	1	180	72	72	?	31	556	575	19	3.1	1.7	English
Rastle et al. (2000)	2a	semantic relatedness	26	lexical decision	32	1	234	43	43	?	18	616	617	1	8.1	7.3	English
Rastle et al. (2000)	2b	semantic relatedness	24	lexical decision	32	1	234	72	72	?	18	625	625	0	8	9.3	English
Vigliocco et al (2008)	1a	semantic	23	lexical decision	23	1	25	67	67	?	?	585	598	13	0.2	0.3	English
Zhou & Marslen-Wilson (2000)	1	semantic	44	lexical decision	44	1	184	57	57	?	?	530	572	42	1.7	6.4	Chinese
Zhou & Marslen-Wilson (2000)		semantic		lexical decision	80	1	184	57	57	?	?	518	558	40	1.9	7	Chinese
Zhou & Marslen-Wilson (2000)	2	synonym	57	lexical decision	56	1	186	57	57	?	?	507	543	36	2.6	5.1	Chinese
Zhou & Marslen-Wilson (2000)		mixed		lexical decision	68	1	186	57	57	?	?	509	545	36	2.7	5.8	Chinese
Balota et al. (2008)	6	associative (66%)	32	naming	150	1	300	42	42	8.56	4.83	584	584	0	1.8	1.5	English
Balota et al. (2008)		associative (66%)	32	naming	150	1	300	42	42	8.56	4.83	670	699	29	5.8	6.1	English
Lukatela & Turvey (1994)	1a	associative	39	naming	30	1	120	40	100	24		588	603	15	4.1	4.9	English
Lukatela & Turvey (1994)	1b	associative		naming	30	1	120	40	100	79		577	603	26	1.5	4.1	English
Lukatela & Turvey (1994)	2a	associative	39	naming	30	1	120	40	100	24		522	536	14	0.5	1.5	English
Lukatela & Turvey (1994)	2b	associative		naming	30	1	120	40	100	79		511	527	16	1	2.1	English
Lukatela & Turvey (1994)	4a	associative	45	naming	30	1	120	52	52	24		566	577	11	4	2.4	English
Lukatela & Turvey (1994)	4b	associative		naming	30	1	120	52	52	79		554	564	10	2	2.2	English
Lukatela & Turvey (1994)	5a	associative	54	naming	42	1	120	50	50	16	79	572	583	11	1.6	3.4	English
Lukatela & Turvey (1994)	5b	associative		naming	42	1	120	50	50	92	58	565	575	10	1.9	2.1	English
Lukatela & Turvey (1994)	8a	associative	56	naming	40	1	126	50	50	19	44	559	571	12	1.4	2.5	English
Lukatela & Turvey (1994)	8b	associative		naming	40	1	126	50	50	145	129	546	558	12	5	3.9	English
Lukatela & Turvey (1994)	9a	associative	40	naming	40	1	110	70	70	9		543	553	10	0.8	1.8	English
Lukatela & Turvey (1994)	9b	associative		naming	40	1	110	70	70	232		525	539	14	1.3	1.3	English
O'Seaghdha & Marin (1997)	3	associative	32	naming	60	1	60	57	57	?	?	524	535	11	0.4	1.9	English
Perea & Rosa (2002b)	3a	Asscoiative strength (32%)	24	naming	24	1	66	66	66	?	?	566	568	2	0	0	Spanish
Perea & Rosa (2002b)	3b	Asscoiative strength (32%)	24	naming	24	1	66	66	66	?	?	580	593	13	0	0	Spanish
Perfetti & Tan (1998)	2	semantic	20	naming	96	1	108	43	43	?	?	635	640	5	0	5	Chinese
Perfetti & Tan (1998)		semantic	18	naming	96	1	108	57	57	?	?	634	639	5	3.1	5.1	Chinese
Perfetti & Tan (1998)		semantic	16	naming	96	1	108	85	85	?	?	590	631	41	3.8	5.6	Chinese
Reimer et al (2008)	1	Associative strenght (43%)	52	naming	36	1	60	53	53	?	66	526	541	15	1.3	4.6	English
Reimer et al (2008)	2a	Associative strenght (43%)	33	naming	24	1	72	53	53	?	66	511	523	12	2.7	4.8	English
Reimer et al (2008)	2b	Associative strenght (43%)	27	naming	24	1	72	53	53	?	66	517	529	12	1.6	3.6	English
Reimer et al (2008)	4	Associative strenght (43%)	47	naming	36	1	60	33	33	?	66	496	506	10	2.6	6.5	English
Zhou & Marslen-Wilson (2000)	3	synonym	40	naming	56	1	186	57	57	?	?	582	597	15	0	0	Chinese
Zhou & Marslen-Wilson (2000)		mixed		naming	68	1	186	57	57	?	?	572	590	18	0	0	Chinese
Zhou & Marslen-Wilson (1999)	2	synonyms	40	naming	68	1	167	57	57	?	?	566	582	16	0	0	Chinese
Zhou & Marslen-Wilson (1999)	3	synonyms	40	naming	40	1	130	57	57	?	?	595	582	-13	0	0	Chinese
Zhou & Marslen-Wilson (1999)	4	synonyms	33	naming	48	1	108	57	57	?	?	579	600	21	0	0	Chinese

Appendix B : Stimuli used in Experiments 1 and 2

Target	Trial	Frequency	Rel prime	Unrl prime	LSAreltar	LSAunrltar	FrBNCrel	FrBNCunrl	OrthsimRelTar	OrthsimUnrlTar	FSGReltar	BSGreltar	FrBNCTar
ANSWER	1	HF	RESPONSE	EXERCISE	0.05	0.15	106.33	90.27	209	152	0.49	0.071	140.1
AREA	46	HF	REGION	RECORD	0.06	0.62	99.89	154.8	173	173	0.512	0	350.58
ARGUE	61	HF	DEBATE	FEMALE	0.02	0.46	74.75	87.12	258	258	0.473	0.034	44.6
ART	16	HF	MUSEUM	COFFEE	0	0.71	74.4	63.81	25	25	0.442	0	169.34
BEHIND	31	HF	AHEAD	TREND	0.05	0.61	64.83	28.08	331	369	0.424	0.027	248.02
BLUE	76	HF	SKY	DRY	0.07	0.43	52.82	67.27	37	38	0.522	0.284	105.47
BOOK	2	HF	CHAPTER	QUALITY	0.07	0.25	162.71	170.41	29	29	0.614	0	249.88
BUILDING	47	HF	STRUCTURE	SECRETARY	0.1	0.29	144.4	162.54	56	44	0.415	0.034	195.91
BUY	62	HF	PURCHASE	SHOULDER	0.07	0.49	48.07	51.24	37	37	0.577	0.133	109.41
CAR	17	HF	DRIVE	TRUST	0.05	0.73	91.23	106.47	55	55	0.48	0.122	266.6
CHAIN	32	HF	LINK	WINE	0.06	0.42	55.45	65.76	196	196	0.4	0.106	39.12
CHAIR	77	HF	TABLE	HUMAN	0.05	0.61	207.97	211.67	70	90	0.756	0.314	77.69
CHILD	3	HF	ADULT	PLAIN	0.06	0.42	54.83	43.55	90	90	0.459	0.101	256.91
CHOICE	48	HF	OPTION	MOTION	0.06	0.3	56.89	37.81	133	133	0.635	0.031	126.5
CITY	63	HF	TOWN	GIRL	0.09	0.27	185.7	157.58	75	75	0.529	0.307	242.54
CLOSE	18	HF	SHUT	DIET	0.05	0.44	44.1	44.46	62	62	0.447	0.041	200.5
DAY	33	HF	WEEK	LINE	0.13	0.69	286.19	231.77	37	38	0.473	0.022	607.17
DEATH	78	HF	LIFE	MUST	0.1	0.55	597.4	740.8	62	62	0.485	0.273	222.23
DEMAND	4	HF	SUPPLY	ATTACK	0.08	0.74	101.57	102.12	50	67	0.464	0.148	118.17
DIRTY	49	HF	CLEAN	PHASE	0.01	0.7	63.85	50.7	50	50	0.527	0.288	26.72
DOCTOR	64	HF	MEDICAL	BENEFIT	0.1	0.64	99.94	110.52	74	58	0.516	0	104.67
DONE	19	HF	FINISHED	STRATEGY	0.1	0.51	78.28	64.29	75	42	0.547	0	287.7
EMPIRE	34	HF	ROMAN	RURAL	0.02	0.76	60.69	66.47	78	60	0.456	0.026	39.9
END	79	HF	BEGINNING	COMMUNITY	0.05	0.54	125.9	242.87	50	33	0.747	0	493.47
ENDING	5	HF	CONCLUSION	PROTECTION	0.03	0.11	54	85.69	67	68	0.612	0	25.38
EXIT	50	HF	ENTER	ENJOY	0.11	0.32	55.65	67	354	332	0.568	0.388	13.19
FAST	65	HF	QUICK	MINOR	0.04	0.48	56.22	52.84	40	40	0.408	0.087	79.32
GAS	20	HF	FUEL	HELL	0.01	0.36	44.91	45.94	37	38	0.664	0.154	74.07
HARD	35	HF	DIFFICULT	POLITICAL	0.05	0.36	222.24	332.52	38	38	0.594	0	233.84
HEAR	80	HF	LISTEN	OBTAIN	0.04	0.72	49.89	49.99	53	53	0.506	0.322	124.99
HELP	6	HF	ASSISTANCE	ENTERPRISE	0.05	0.32	46.89	45.33	34	49	0.696	0	386.56
HIT	51	HF	STRIKE	GUILTY	0.1	0.3	58.78	44.04	69	69	0.447	0	37.93
HOME	66	HF	HOUSE	HORSE	0.15	0.43	514.04	79.41	668	668	0.582	0.333	526.53
HURT	21	HF	INJURY	ASPECT	0.03	0.29	49.78	45.73	173	233	0.448	0.042	14.97
JAIL	36	HF	PRISON	SPRING	0.06	0.71	68.9	63.81	53	53	0.424	0.261	13.27
JOB	81	HF	EMPLOYMENT	THROUGHOUT	0.15	0.65	111.54	132.59	30	30	0.605	0.016	210.97
KILL	7	HF	MURDER	SQUARE	0.08	0.3	64.45	71.44	33	33	0.564	0.287	48.77
KING	52	HF	CROWN	FRUIT	0.03	0.48	56.64	42.25	62	62	0.471	0.016	177.88
LEAD	67	HF	FOLLOW	SECTOR	0.15	0.36	99.6	90.22	53	53	0.63	0.271	154.25

LET	22	HF	ALLOW	PRICE	0.07	0.25	121.67	191.24	55	55	0.461	0.283	245.14
LOSE	37	HF	FIND	WORD	0.12	0.33	410.28	191.09	50	75	0.4	0.223	64.18
LUNCH	82	HF	BREAKFAST	TERRITORY	0.02	0.62	45.27	34.1	22	28	0.473	0.013	52.05
MAD	8	HF	ANGER	AGENT	0.04	0.23	42.72	46.29	55	55	0.412	0	31.07
MINUTE	53	HF	HOUR	FEAR	0.19	0.51	103.94	96.87	53	53	0.469	0.265	74.41
MONEY	68	HF	FINANCIAL	PRESIDENT	0.07	0.24	176.22	175.75	42	99	0.412	0	342.91
MOUNTAIN	23	HF	HILL	RACE	0.08	0.3	72.79	84.87	42	42	0.428	0.265	42.49
MOVIE	38	HF	FILM	COLD	0.03	0.65	106.29	120.18	84	62	0.543	0.195	19.33
NEED	83	HF	NECESSARY	EDUCATION	0.15	0.39	193.65	276.58	415	145	0.473	0	521.25
NEWSPAPER	9	HF	ARTICLE	SURFACE	0.02	0.37	72.02	98.25	76	51	0.419	0.127	53.14
NIGHT	54	HF	EVENING	PROJECT	0.02	0.71	141.63	159.61	219	232	0.417	0	353.47
NINE	69	HF	EIGHT	BROWN	0.23	0.74	122.74	91.19	84	62	0.634	0	86.06
OCEAN	24	HF	SEA	WIN	0.02	0.52	140.11	108.8	205	235	0.456	0.291	21.45
OFFICE	39	HF	POST	MARK	0.08	0.46	94.53	124.49	53	33	0.426	0	266.9
OLD	84	HF	YOUNG	LARGE	0.19	0.44	353.44	363.07	55	55	0.595	0.236	547.49
OPEN	10	HF	CLOSED	MIDDLE	0.15	0.75	103.71	129.61	73	53	0.678	0	309.89
OWE	55	HF	DEBT	SELL	0.09	0.47	58.37	72.2	66	66	0.46	0.162	11.77
PAINTER	70	HF	ARTIST	THIRTY	0.05	0.9	44.11	42.82	104	89	0.437	0.204	13.52
PAPER	25	HF	DOCUMENT	OCCASION	0.09	0.25	53.7	56.11	47	47	0.408	0	166.56
PLACE	40	HF	PUT	PAY	0.13	0.4	475.04	202.83	325	350	0.478	0.062	499.4
PLANE	85	HF	AIRCRAFT	DISTRICT	0.03	0.66	66.42	74.82	47	31	0.408	0	36.2
POLICE	11	HF	OFFICER	HOLIDAY	0.1	0.67	93.75	75.41	443	243	0.466	0.031	289.01
PRESENT	56	HF	PAST	PART	0.27	0.62	259.23	520.76	533	533	0.426	0.138	234.78
QUESTION	71	HF	ASK	AGE	0.12	0.7	170.02	229.03	37	37	0.422	0.034	255.4
QUIET	26	HF	SILENCE	DISPLAY	0.06	0.67	65.26	67.49	69	52	0.413	0	65.4
RIGHT	41	HF	WRONG	HAPPY	0.3	0.59	147.94	110.43	90	70	0.723	0.392	595.09
SCARE	86	HF	AFRAID	PARTLY	0.04	0.43	59.74	60.81	133	169	0.604	0.123	5.54
SEVEN	12	HF	SIX	SIR	0.24	0.8	238.6	195.33	325	325	0.434	0.047	127.99
SHERIFF	57	HF	DEPUTY	PLENTY	0.09	0.43	42.6	47.79	58	58	0.679	0.167	10.25
SHORT	72	HF	LONG	LOOK	0.13	0.66	514.44	449.96	62	50	0.536	0.222	192.72
SIT	27	HF	STAND	SOUND	0.21	0.54	107.81	126.32	350	325	0.534	0.348	72.59
STAIRS	42	HF	STEPS	SALES	0	0.47	74.17	108.52	637	546	0.526	0.146	36.61
STAY	87	HF	REMAIN	AFFECT	0.13	0.25	97.67	51.06	53	73	0.784	0.106	122.24
STRONG	13	HF	POWERFUL	ACADEMIC	0.07	0.56	78.63	53.07	66	38	0.587	0	170.84
TALK	58	HF	DISCUSS	RECEIVE	0.12	0.3	57.86	78.93	29	29	0.689	0.016	153.75
TEACHER	73	HF	PROFESSOR	CHARACTER	0.02	0.11	55.28	91.28	244	544	0.511	0.074	89.77
TELEVISION	28	HF	COMMERCIAL	INDUSTRIAL	0.07	0.29	87.6	124.94	90	110	0.414	0.014	102.53
THIN	43	HF	THICK	BRAIN	0.04	0.7	48.51	50.07	599	376	0.682	0.084	55.9
THING	88	HF	OBJECT	FACTOR	0.09	0.09	67.27	66.69	60	60	0.412	0.189	261.09
THOUGHT	14	HF	IDEA	PLAY	0.18	0.39	212.69	211.01	29	29	0.443	0.122	532.26
TODAY	59	HF	YESTERDAY	AUTHORITY	0.12	0.37	196.96	190.86	408	265	0.438	0.111	235.46
TOUCH	74	HF	CONTACT	CAPITAL	0.03	0.27	108.24	145.53	86	69	0.416	0	68.13
TRY	29	HF	ATTEMPT	MACHINE	0.09	0.37	124.66	89.3	41	21	0.749	0.13	191.56
TWICE	44	HF	ONCE	FACE	0.28	0.52	278.71	373.76	376	376	0.612	0.264	62.5
UGLY	89	HF	PRETTY	MEMORY	0.11	0.5	72.46	80.39	233	233	0.473	0.291	13.96
WANT	15	HF	DESIRE	BELIEF	0.06	0.37	59.57	55.92	33	33	0.61	0.278	435.66
WAR	60	HF	BATTLE	HAPPEN	0.08	0.51	71.93	79.59	47	47	0.469	0.026	291.19
WEIGHT	75	HF	SCALE	SLEEP	0.06	0.18	79	75.45	60	60	0.53	0.014	88.28
WEIRD	30	HF	STRANGE	PREVENT	0	0.49	68.84	73.53	69	69	0.426	0.312	8.96
WIDE	45	HF	NARROW	PROFIT	0.1	0.58	54.04	61.93	53	53	0.406	0.179	129.07
YEARLY	90	HF	ANNUAL	DOUBLE	0.1	0.43	87.2	77.37	83	83	0.707	0	4.44

BALL	91	LF	BOUNCE	BUFFET	0.05	0.64	5.03	6.06	323	323	0.564	0.06	73.79
BANK	136	LF	TELLER	STUPOR	0.04	0.8	1.74	1.05	33	33	0.814	0.028	189.52
BASS	151	LF	TREBLE	REVISE	0.02	0.37	4.27	3.52	53	53	0.487	0.095	20.37
BATH	106	LF	TUB	RIB	0	0.61	2.79	4.64	95	66	0.493	0.091	37.69
BEAR	121	LF	CUB	RUT	-0.03	0.74	1.72	0.98	66	66	0.585	0.051	58.65
BED	166	LF	MATTRESS	LITERATE	0.02	0.63	4.97	3.87	37	37	0.539	0.031	156.48
BELT	92	LF	BUCKLE	BLEACH	0.05	0.38	2.65	2.58	423	423	0.667	0.213	21.78
BET	137	LF	WAGER	DEFER	-0.03	0.05	1.58	2	55	55	0.606	0.073	18.39
BLOOD	152	LF	DONOR	DOGMA	0	0.41	6.69	2.68	170	150	0.524	0.067	107.47
BODY	107	LF	ANATOMY	ECOLOGY	0	0.38	5.26	6.61	245	245	0.607	0	272.03
BONE	122	LF	MARROW	PARROT	0.01	0.84	3.28	3.98	53	53	0.777	0.121	25.24
BOX	167	LF	CARDBOARD	ROUNDABOUT	0.09	0.47	7.49	4.34	133	123	0.559	0.092	84.24
BOY	93	LF	SCOUT	VOTER	0.03	0.25	3.6	3.24	55	55	0.568	0.011	129.71
BRUSH	138	LF	COMB	CUBE	0.04	0.29	4.23	3.79	62	84	0.636	0.163	19.7
BUSH	153	LF	SHRUB	TRASH	0.06	0.36	2.69	2.27	307	376	0.503	0.063	40.7
CARD	108	LF	POKER	SPICY	-0.02	0.08	2.37	2.14	62	62	0.414	0.061	53.01
CARPET	123	LF	RUG	RUM	0.07	0.56	7.64	4.58	47	47	0.468	0.248	23.28
CAT	168	LF	KITTEN	GALLOP	0.02	0.61	2.44	2.66	47	47	0.789	0.16	37.47
CHICKEN	94	LF	HEN	FEN	0.03	0.52	4.5	6	361	341	0.453	0.022	17.85
CHOCOLATE	139	LF	FUDGE	POISE	0.07	0.26	1.39	1.76	222	236	0.517	0.014	17.92
CLOTHES	154	LF	HANGER	ATTAIN	0.03	0.06	1.42	5.01	74	58	0.521	0.054	74.89
COLOUR	109	LF	HUE	NAP	0.06	0.36	2.36	2.15	47	50	0.547	0.02	117.1
COOK	124	LF	CHEF	CULT	0.04	0.43	7.19	9.98	345	345	0.622	0.047	39.67
COPY	169	LF	XEROX	PEDAL	0.01	0.48	2.65	3.87	62	62	0.763	0.083	59.05
CRAZY	95	LF	INSANE	EXCITE	0.04	0.16	4.39	2.39	60	60	0.523	0.209	18.36
CURTAINS	140	LF	DRAPES	OPTICS	0	0.43	1.34	1.46	260	275	0.55	0.196	20.3
DEVIL	155	LF	DEMON	DECOR	0.05	0.3	3.2	3.28	460	460	0.553	0.04	17.53
DIRECTION	110	LF	COMPASS	NAUGHTY	0.04	0.54	6.72	5.09	64	64	0.519	0.029	92.33
DOOR	125	LF	KNOB	SMOG	0	0.37	2.63	1.51	75	75	0.672	0.139	253.24
DRAW	170	LF	SKETCH	OUTFIT	0.02	0.78	8.04	8.71	33	33	0.764	0.108	72.63
ENEMY	96	LF	FOE	WED	0.08	0.4	4.14	6.16	55	55	0.401	0.197	37.21
ENERGY	141	LF	KINETIC	INCLINE	0.01	0.66	2.3	2.23	197	197	0.612	0	131.07
FIRE	156	LF	INFERNO	SIGNIFY	0.07	0.38	1.42	3.58	156	136	0.497	0	139.74
FLOOR	111	LF	TILE	IDLE	0.05	0.37	3.91	7.28	62	62	0.578	0.17	117.76
FOOD	126	LF	CAFETERIA	DESERVING	0.02	0.32	1.36	2.98	38	38	0.593	0	198.25
FOOT	171	LF	TOE	TOR	0.17	0.67	6.33	2.41	180	180	0.605	0.235	74.12
FOREVER	97	LF	INFINITY	RIGIDITY	0	0.09	2.88	2.34	57	57	0.565	0.034	18.77
FRIEND	142	LF	PAL	TOW	0.07	0.39	5.5	4.05	25	25	0.772	0.089	175.99
GAME	157	LF	JEOPARDY	SADISTIC	-0.02	0.01	3.73	1.57	58	42	0.463	0	154.31
GOD	112	LF	CREATOR	BUFFALO	0.03	0.65	5.82	3.36	41	41	0.503	0.034	217.57
GREAT	127	LF	TERRIFIC	EXTERIOR	0.09	0.24	6.14	7.36	124	124	0.497	0.042	462.79
GROSS	172	LF	DISGUSTING	ADJUSTABLE	0.02	0.04	5.92	4.07	65	38	0.455	0.193	25.95
HAND	98	LF	GLOVE	FIVER	0.01	0.35	3.97	3.7	40	40	0.552	0.048	367.22
HEART	143	LF	TRANSPLANT	CONTRADICT	0.01	0.24	5.04	2.94	325	325	0.4	0	146.54

HUNGRY	158	LF	STARVE	ADVERT	0.01	0.49	2.75	3.31	67	67	0.469	0.244	18.44
JUMP	113	LF	HOP	DIP	0.09	0.7	5.41	7.16	246	246	0.417	0.139	24.16
KISS	128	LF	HUG	LAG	0.03	0.53	3.66	3.5	38	38	0.411	0.224	26.69
LAND	173	LF	ACRE	WARY	0.05	0.58	5.91	8.87	75	75	0.675	0.02	217.11
LEAVE	99	LF	DEPART	STEREO	0.06	0.42	4.76	5.65	78	78	0.619	0	195.71
LETTERS	144	LF	ALPHABET	ALIENATE	0.06	0.8	3.07	1.28	190	204	0.412	0.144	81.39
LIGHT	159	LF	BULB	FLAP	0.06	0.49	4.23	4.45	62	62	0.788	0.212	214.72
LOVE	114	LF	ADORE	MELON	0.08	0.46	1.73	2.15	264	218	0.565	0.011	233.04
MAGIC	129	LF	WAND	WARE	0.09	0.41	1.42	2.51	62	62	0.466	0.102	34
MUSCLE	174	LF	FLEX	LEAK	-0.03	0.43	2.65	5.76	173	173	0.458	0.055	18.46
MUSIC	100	LF	HARP	WADE	0.03	0.57	2.93	4.72	40	40	0.412	0	158.6
PEN	145	LF	INK	GEL	-0.01	0.34	8.26	7.42	83	83	0.695	0.152	20
PENNY	160	LF	CENT	OMEN	0.05	0.24	1.28	1.74	196	196	0.486	0	17.9
PERIOD	115	LF	COMMA	BLINK	0	0.12	1.09	2.46	60	60	0.407	0.079	258.18
PHONE	130	LF	DIAL	BLUR	0.06	0.55	4.45	3.7	40	40	0.455	0.028	67.75
POUND	175	LF	OUNCE	PSALM	0.07	0.54	3.41	2.35	310	340	0.533	0.115	38.56
PULL	101	LF	TUG	GUT	0.08	0.48	5.66	9.02	66	66	0.58	0.133	41.61
ROOF	146	LF	SHINGLE	CAPSULE	0.06	0.44	2.88	2.23	29	29	0.611	0.118	42.25
ROSE	161	LF	THORN	CHORD	0.05	0.24	4.84	6.21	151	151	0.42	0.048	123.14
ROUND	116	LF	OVAL	COIL	-0.01	0.43	7.01	4.39	62	62	0.408	0	273.7
RUN	131	LF	JOG	TOT	-0.06	0.39	1.98	1.83	50	50	0.783	0.14	220.82
SCHOOL	176	LF	CAMPUS	HURDLE	0.01	0.35	6.43	5.99	83	83	0.466	0	368.56
SHIRT	102	LF	BLOUSE	MANTLE	0.08	0.64	5.59	6.15	60	60	0.647	0.135	28.73
SING	147	LF	HUM	HEM	0.06	0.38	3.65	3.31	38	38	0.486	0.033	18.33
SMALL	162	LF	SHRINK	SORROW	0.08	0.21	3.99	6.08	330	330	0.486	0	470.2
SMART	117	LF	GIFTED	DENOTE	-0.02	0.09	5.42	3	60	60	0.459	0	18.56
SORRY	132	LF	APOLOGY	NOVELTY	0.05	0.29	7.18	5.76	249	249	0.578	0.212	77.68
SPACE	177	LF	ASTRONAUT	DENTISTRY	0.03	0.76	1.07	0.69	56	56	0.526	0.025	131.72
STAR	103	LF	TWINKLE	RECYCLE	0.01	0.52	1.57	1.79	47	47	0.662	0.026	70.35
STILL	148	LF	MOTIONLESS	INSECURITY	0.16	0.47	4.34	4.08	145	105	0.513	0.086	744.62
STOP	163	LF	BRAKE	DWARF	0.04	0.4	5.79	6.64	40	40	0.412	0	139.64
STORY	118	LF	FABLE	GLAZE	0.02	0.57	1.52	1.83	50	50	0.481	0.014	141.47
STREET	133	LF	BOULEVARD	BRIDEGROOM	0.03	0.57	2.42	1.61	60	55	0.587	0	202.71
SUN	178	LF	SHINE	STING	0.04	0.49	8.38	6.15	350	350	0.449	0.087	121.96
SWEET	104	LF	SOUR	SCAN	0.02	0.45	7.17	6.99	332	332	0.405	0.372	37.08
TEETH	149	LF	GUMS	CRAB	0.03	0.92	1.77	3.47	40	40	0.705	0.083	49.19
TENNIS	164	LF	RACKET	PUPPET	-0.01	0.56	3.98	3.14	133	133	0.504	0.186	30.17
TEST	119	LF	QUIZ	HARE	0.04	0.1	4.74	4.72	50	75	0.792	0.11	143.52
TRAIN	134	LF	RAILROAD	DILATION	0	0.66	1.28	0.27	231	273	0.5	0.045	81.95
TRIP	179	LF	VACATION	COERCION	-0.02	0.52	3.18	3.66	58	58	0.419	0.297	48.19
UNDERSTAND	105	LF	COMPREHEND	FOREGROUND	0.04	0.52	3.97	3.26	400	460	0.829	0.311	149.38
WALK	150	LF	PEDESTRIAN	EMIGRATION	0	0.39	5.28	3.77	34	34	0.597	0	98.42
WATER	165	LF	HOSE	DICE	0.02	0.24	2.87	3.5	62	62	0.473	0	358.74
WILD	120	LF	TAME	FAKE	0.1	0.7	3.84	6.1	50	50	0.4	0.063	59.73
WINDOW	135	LF	SILL	CITE	0.03	0.61	2.5	3.15	53	53	0.682	0.128	107.45
WORLD	180	LF	GLOBE	DECAY	0.05	0.22	7.32	11.42	90	70	0.679	0.182	629.39