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Using the speeded word fragment completion task to examine semantic priming

Tom Heyman · Simon De Deyne · Keith A. Hutchison · Gert Storms

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Abstract The present research investigates semantic priming with an adapted version of the word fragment completion task. In this task, which we refer to as the speeded word fragment completion task, participants need to complete words such as lett_ce (*lettuce*), from which one letter was omitted, as quickly as possible. This paradigm has some interesting qualities in comparison with the traditionally used lexical decision task. That is, it requires no pseudowords, it is more engaging for participants, and most importantly, it allows for a more fine-grained investigation of semantic activation. In two studies, we found that words were completed faster when the preceding trial comprised a semantically related fragment such as tom_to (*tomato*) than when it comprised an unrelated fragment such as guit_r (*guitar*). A third experiment involved a lexical decision task, to compare both paradigms. The results showed that the magnitude of the priming effect was similar, but item-level priming effects were inconsistent over tasks. Crucially, the speeded word fragment completion task obtained strong priming effects for highly frequent, central words, such as *work*, *money*, and *warm*, whereas the lexical decision task did not. In a final experiment featuring only short, highly frequent words, the lexical decision task failed to find a priming effect, whereas the fragment completion task did obtain a robust effect. Taken together, these results suggest that the speeded word fragment completion task may prove a viable alternative for examining semantic priming.

T. Heyman · S. De Deyne · G. Storms
University of Leuven, Leuven, Belgium

K. A. Hutchison
Montana State University, Bozeman, MT 59717, USA

T. Heyman (✉)
Department of Psychology, University of Leuven, Tiensestraat 102, 3000 Leuven, Belgium
e-mail: tom.heyman@ppw.kuleuven.be

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Semantic priming is the finding that the processing of a target (e.g., a picture, a word,…) is enhanced when preceded by a semantically related prime (also a picture, a word,…), relative to an unrelated prime. For instance, the presentation of the word *cat* facilitates processing of the subsequently presented word *dog*. One of the debates in the semantic priming literature concerns the source of the priming effect (Hutchison, 2003; Lucas, 2000). The (unresolved) issue concerns the type of relation between concepts that is necessary for priming to occur. That is to say, words can be associatively related, as evidenced by association norms, or instead share certain features. Returning to the *cat–dog* example, both cats and dogs have four legs, two eyes, are pets, and so on, and thus they are related in terms of feature overlap (see, e.g., McRae & Boisvert, 1998). Moreover, the strongest associate of *cat* is *dog*; hence, both concepts are also associatively related. Whether priming is driven by word associations or feature overlap (or something else) is an important question because it has significant repercussions for theories about the organization of the mental lexicon.

The most frequently used paradigms to examine these issues are the lexical decision task, in which participants have to decide whether letter strings form existing words or not, and, to a lesser extent, the naming task, in which participants read words aloud (see the reviews of Hutchison, 2003; Lucas, 2000; Neely, 1991). The experimental designs further vary in the degree to which they allow automatic and controlled processes. The latter processes are strategic and they come into play when the prime–target coupling (e.g., *cat–dog*) is made explicit (Jones, 2010). This is for instance the case in the standard lexical decision task, in which participants are required to respond only to the second item of the pair (i.e., the target, *dog*) and not to the first (i.e., the prime, *cat*). Strategic effects are volatile and vary over subjects, whereas automatic processes are ubiquitous (but see Besner, Stolz, & Boutilier, 1997; Brown, Roberts, & Besner, 2001, for arguments against the automaticity of semantic priming). Thus, automatic processes are thought to reliably reflect the structure of the mental lexicon (Lucas, 2000). Hence, considerable effort has been put into developing methodologies that prevent controlled processes. One method to reduce strategic effects is the use of a *continuous* lexical decision task (McNamara & Altarriba, 1988; Shelton & Martin, 1992). Here, prime–target pairs are decoupled by asking participants to respond to all presented words. In other terms, all words then function both as a prime (for the next presented word) and as a target (where the previously presented word was the prime).

In this study, we present a different approach. Our approach is partly motivated by the fact that there is little consensus regarding the nature of semantic priming. A possible explanation for the divergent and sometimes unreplicated findings (see Hutchison, 2003; Lucas, 2000) is that the experimental paradigms are not sensitive enough to detect or tease apart subtle effects. The widely used lexical decision task may rely on more superficial processing of words, whereas deeper semantic processing may be necessary to fully uncover the structure of the mental lexicon. Hence, in this study, we used a different method to examine semantic priming. It is an adaptation of the word fragment completion task, a task that has mainly been used in implicit memory studies (see, e.g., Bassili, Smith, & MacLeod, 1989; Challis & Brodbeck, 1992; McDermott, 1997; Roediger & Challis, 1992; Weldon, 1993). There are several variants of the word fragment completion task, but the general idea is that participants are presented with words from which one or more letters are omitted (e.g., r_d or _orn_d_). Participants are then assigned to fill in the gap(s). In this article, we examine semantic priming using relatively simple stimuli with only one blank space. Participants could complete the fragment with either one of five (Experiment 1) or one of two (Experiments 2 and 4) possible letters, and stimuli were constructed such that there was only one correct completion. The task conceptually resembled a continuous lexical decision task, in that participants had to complete both prime and target words. For instance, on trial *n* participants are presented with the fragment tom_to (which should be completed as *tomato*) and on trial *n+1* they are presented with lett_ce (which should be completed as *lettuce*). For the sake of clarity, we will therefore coin the term continuous speeded word fragment completion task to refer to the experimental paradigm in this study. As in a (continuous) lexical decision task, the main dependent variable is reaction time, because accuracy will be near perfect. Hence, it is expected that lett_ce will be completed more quickly when it is preceded by a semantically related stimulus such as tom_to than when it is preceded by an unrelated stimulus such as guit_r (which should be completed as *guitar*).

Our main goal is to present a task to study semantic access in the mental lexicon. We posit that the speeded word fragment completion task is a good candidate because it involves more elaborate processing, which in turn allows for a finer-grained investigation of semantic activation. In the lexical decision task, on the other hand, shallow processing of letter strings may be sufficient to discriminate words from nonwords (Rogers, Lambon Ralph, Hodges, & Patterson, 2004), thereby limiting the facilitatory effect of a related prime. Because the speeded word fragment completion task is assumed to be more effortful, a related prime has more potential to exert its influence. A similar argument has been made by Balota, Yap, Cortese, and Watson (2008), for visually degraded target words in a lexical decision task and a speeded naming task. People rely more on information conveyed by the prime if target processing is hindered due to visual degradation. The same rationale holds for omitting a letter from a word (see the General discussion for further discussion).

In addition, the speeded word fragment completion task has some other potentially attractive qualities. First of all, it is likely more engaging than the lexical decision task, but not to the extent that it becomes burdensome. This, in turn, should enhance the intrinsic motivation of participants and prompt a greater focus (Deci & Ryan, 1985).

Secondly, Neely and Keefe (1989) argued that participants in a lexical decision task might use information about whether the considered letter string is semantically related to the preceding letter string to reduce their response time (i.e., a retrospective semantic matching strategy). Because related word–nonword pairs (e.g., *boy–girk*) are almost never included in priming experiments, the presence of a semantic relation between two consecutively presented letter strings signals that the correct answer for the latter string is always *word*. If there is no such relation, the second letter string is a word *or* a nonword. In fact, when the proportion of nonwords in the experiment is high, then the absence of a relation between two consecutive letter strings indicates that the second letter string is more likely to be a nonword. It is possible that participants notice these contingencies, which in turn yields strategic priming effects that are inseparable from the automatic priming effects on which researchers usually focus. It has been suggested (see, e.g., Neely & Keefe, 1989) that the naming task eliminates such semantic matching. That is, detection of a semantic relation between prime and target does not aid target pronunciation (but see Thomas, Neely, & O'Connor, 2012). Similarly, in the speeded word fragment completion task, a semantic relation between two words on consecutive trials is not predictive of the correct response to the latter word fragment. The fact that *tomato* and *lettuce* are related does not give information about which letter is missing in the fragment lett_ce (see the General discussion for further elaboration of this point).

Finally, the speeded word fragment completion task obviates the need to construct pseudowords. Many researchers prefer to have an equal number of words and pseudowords in a lexical decision task in order to avoid a response bias. The absence of pseudowords makes the speeded word fragment completion task more efficient, which allows the inclusion of more experimental items (and/or additional tasks) within the same session.

Taken together, we believe that this task has not only the potential to uncover fine-grained semantic effects, which are obtained with limited success within a lexical decision framework; it also has some appealing methodological characteristics. The present study sought to explore the use of this paradigm within the context of semantic priming research. To this end, Experiments 1 and 2 examine whether a priming effect could be obtained with the speeded word fragment completion task using, respectively, a five-alternative and a two-alternative forced-choice task. Experiment 3 involves a lexical decision task with the exact same items as Experiment 2. This allows us to compare both tasks in terms of (A) reliability of the response times, (B) average response time and number of error responses, (C) magnitude and consistency of priming effects, and (D) predictors of response times. Finally, in Experiment 4, we compare both tasks directly in a counterbalanced design featuring only short, high-frequency words.

Experiment 1

Method

Participants Participants were 40 first-year psychology students of the University of Leuven (7 men, 33 women, mean age 18 years) who participated in return for course credit. All participants were native Dutch speakers.

Materials A total of 76 related prime–target pairs such as tom_to–lett_ce (*tomato–lettuce*) were constructed (see Table 1 for item characteristics and Appendix A for all the pairs). All stimuli were Dutch word fragments. Primes and targets were always category coordinates. Categories ranged from fruits and musical instruments to mammals, tools, professions, and so on. The pairs were either selected from the norms of De Deyne et al. (2008) or derived from the Dutch Word Association Database (De Deyne et al., 2013). Moreover, prime–target pairs had a forward association strength that ranged from 3 % to 30 %, which was also obtained from the Dutch Word Association Database. De Deyne et al. (2013) asked participants to provide three associations per cue, instead of the single-response paradigm that is traditionally used (see, e.g., Nelson et al., 2004). As a result, the measures of association strength are more sensitive to moderate and weakly associated word pairs than is the single-response method. In addition, another 76 unrelated filler pairs were constructed.

All word fragments were generated by omitting one vowel from a Dutch noun. Only word fragments that had a unique correct response were used. Of the 76 critical targets, 16 required an *a* response, 22 an *e* response, 18 an *i* response, 13 an *o* response, and 7 a *u* response. We opted to delete vowels because of their high frequency of occurence. That is, in a rank ordering of the most common letters based on the SUBTLEX-NL corpus (Keuleers, Brysbaert, & New, 2010) the vowels *a*, *e*, *i*, *o*, and *u* are, respectively, third, first, seventh, sixth, and sixteenth. In addition, the instructions are rather straightforward and easy to remember.

Two lists were created, such that a random half of the 76 critical targets were preceded by their related prime in List A, whereas in List B they were preceded by an unrelated word, and vice versa. The 38 unrelated pairs for each list were constructed by randomly recombining primes and targets, with two constraints. The first is that the resulting prime–target pairs were not category coordinates and lacked any forward or backward association between prime and target. Second, a fraction of the related prime–target pairs were response congruent, meaning that the same vowel was missing in both the prime and the target. The unrelated pairs were created in a way that they matched in terms of response congruency. When a related pair was response congruent or incongruent, so was the corresponding unrelated pair. Altogether, each list consisted of 76 critical prime–target pairs (38 related pairs and 38 unrelated pairs) and an additional 76 unrelated filler pairs.

Procedure

Participants were randomly assigned to one of the two lists. Twenty participants received List A and 20 received List B. The task itself was a continuous speeded word fragment completion task. The continuous nature of the task breaks the 152 pairs down to 304 trials. On each trial, participants were presented with one word fragment. Primes were always shown on odd-numbered trials and targets on even-numbered trials. The order of the pairs within the experiment was random, and varied over participants.

On every trial, participants saw a word from which one letter was omitted. They were informed that the missing letter was always a vowel. Participants had to complete the word by pressing either *a*, *e*, *u*, *i*, or *o* on an AZERTY keyboard. The instructions stressed both speed and accuracy. Every word fragment was displayed in the center of the screen and remained present until a response was made. The intertrial interval was 500 ms. Before the experimental phase, participants performed 20 practice trials. The practice trials were identical to the experimental trials except that 20 new, semantically unrelated word fragments were utilized. The experiment was run on a Dell Pentium 4 with a 17.3-in. CRT monitor using Psychopy (Peirce, 2007). It was part of

Table 1 Descriptive statistics for the critical prime–target pairs in Experiment 1 (second column), Experiments 2 and 3 (third column), and Experiment 4 (fourth column)

Factor	Mean (*SDs* in parentheses) for Experiment 1	Mean (*SDs* in parentheses) for Experiments 2 and 3	Mean (*SDs* in parentheses) for Experiment 4
Target length	5.91 (1.60)	5.31 (0.70)	4.20 (0.69)
Target contextual diversity	2.36 (0.69)	2.46 (0.80)	3.16 (0.53)
Prime length	6.12 (1.85)	5.42 (0.73)	6.35 (1.37)
Prime contextual diversity	2.05 (0.76)	1.89 (0.64)	2.08 (0.67)
Forward association strength	.08 (.05)/ .12 (.12)	.10 (.06)/ .16 (.14)	.17 (.07)/ .31 (.18)
Backward association strength	.03 (.04)/ .04 (.07)	.04 (.06)/ .06 (.12)	.04 (.06)/ .05 (.11)

Note—Contextual diversity is the log-transformed number of contexts in which a certain word occurs (Adelman, Brown, & Quesada, 2006). Forward and backward association strength were derived from the Dutch Word Association Database (De Deyne, Navarro, & Storms, 2013). De Deyne et al. (2013) collected three associations per cue, which allows for two strength measures. The figures before the forward slash are derived from all three responses and are usually lower than measures relying on single-response paradigms (see, e.g., Nelson, McEvoy, & Schreiber, 2004). The figures after the forward slash are solely based on the first associations and are thus comparable with the Nelson et al. (2004) norms.

a series of unrelated experiments and took approximately 15 min.

Results and discussion

First, the split-half reliability of the response times to the 76 critical targets was calculated using the Spearman–Brown formula. Split-half correlations for List A and List B separately were obtained for 10,000 randomizations of the participants. The resulting reliabilities, averaged over the 10,000 randomizations, were .92 for List A and .87 for List B, which is rather high for response times. For the log-transformed response times, the reliabilities were .94 and .91, respectively.

Erroneously completed targets (3.4 % of the data) and targets preceded by an incorrectly completed prime were not included in the analysis (5.3 % of the data). Furthermore, responses faster than 250 ms and slower than 4,000 ms were removed, after which an individual cutoff value for each participant was computed as the mean response time plus 3 standard deviations. Response times exceeding this criterion were also excluded (resulting in the discarding of another 4.1 % of the data). This led to an average response time of 963 ms (*SD* = 343). The specified exclusion criteria are similar to regular priming studies using the standard lexical decision task, except for the exclusion of target trials following incorrect prime completion. This has to do with the continuous nature of the task: Posterror slowing and/or subpar prime processing conceivably obscure target response times and/or priming effects.

The log-transformed response times were then fitted using a mixed-effects model. The response times were regressed on four predictors: one critical predictor called Relatedness, which is a binary variable indicating whether the target (lett_ce , *lettuce*) was preceded by a related prime (tom_to, *tomato*) or an unrelated prime (guit_r, *guitar*), and three covariates—namely, Contextual Diversity of the target (CD Target,[1] acquired from Keuleers, Brysbaert, & New, 2010), Word Length of the target in number of characters (Length Target), and the log-transformed response time to the prime (RT Prime). To facilitate the interpretation of the effects, CD Target, Length Target, and RT Prime were *z*-transformed. Furthermore, Relatedness was coded such that targets preceded by a related prime served as a baseline. Thus, the intercept should be interpreted as the expected response time to a target with an average length (≈6 characters) and an average contextual diversity (≈2.4) that was preceded by a related prime with an average response time (≈1,104 ms). For the random structure of the model, we followed the guidelines from Barr, Levy, Scheepers, and Tily (2013). We included a random intercept for participants and items (i.e., the 76 critical targets) and by-item and by-participant random slopes of Relatedness.[2] The analyses were carried out in R (version 2.15.2) (R Development Core Team, 2011), employing the lme4 package (Bates & Sarkar, 2007). Markov Chain Monte Carlo *p*-values (pMCMC) and 95 % highest posterior density intervals (HPD95) were obtained with the pvals.fnc() function of the languageR package, with 10,000 iterations (Baayen, 2008). Besides *p*-values based on MCMC sampling, we also report the *t*-statistic and treat it as a *z*-statistic to derive *p*-

[1] Contextual diversity is the log-transformed number of contexts in which a certain word occurs. This variable has been shown to be more informative than word frequency (Adelman et al., 2006; Brysbaert & New, 2009).

[2] Originally, the model also allowed the random intercepts and random slopes to be correlated. However, we obtained high correlations (i.e., 1.00), which indicate that the model is overparameterized (Baayen, Davidson, & Bates, 2008). We thus simplified the model by removing the correlation parameters, as suggested by Baayen and colleagues. Random effects for the control predictors were not included in the model because it would increase the number of parameters without being considered essential (Barr et al., 2013).

values; this is because pMCMC-values can be somewhat liberal (Barr et al., 2013).

The results are summarized in Fig. 1, which depicts the 95 % highest posterior density interval for the fixed effects. Note that the HPD95 of the intercept, which ranged from 6.76 to 6.85, is not presented because it would have distorted the *x*-axis. Figure 1 shows that all predictors have a HPD95 that excludes zero. Hence, there is a significant priming effect (pMCMC < .001, $t = 4.76$, $p < .001$). To grasp the magnitude of the effect, one can derive model predictions based on the point estimates of the fixed effects (i.e., the dots in Fig. 1; the estimate of the intercept was 6.8). The expected response time for the average participant and the average target following an average related prime equals 903 ms. The response time increases to 946 ms when the target is preceded by an unrelated prime. In other words, there is a priming effect of 43 ms.

To facilitate the comparison with other studies, we also conducted an analysis on the untransformed response times using only Relatedness as a predictor. The model again included random intercepts and random slopes. The results confirmed that there was a significant priming effect (pMCMC < .001, $t = 3.85$, $p < .001$). The magnitude of the effect according to the point estimate was 56 ms.

In sum, Experiment 1 shows that the speeded word fragment completion task can capture semantic priming effects. However, this study is somewhat limited in scope because all

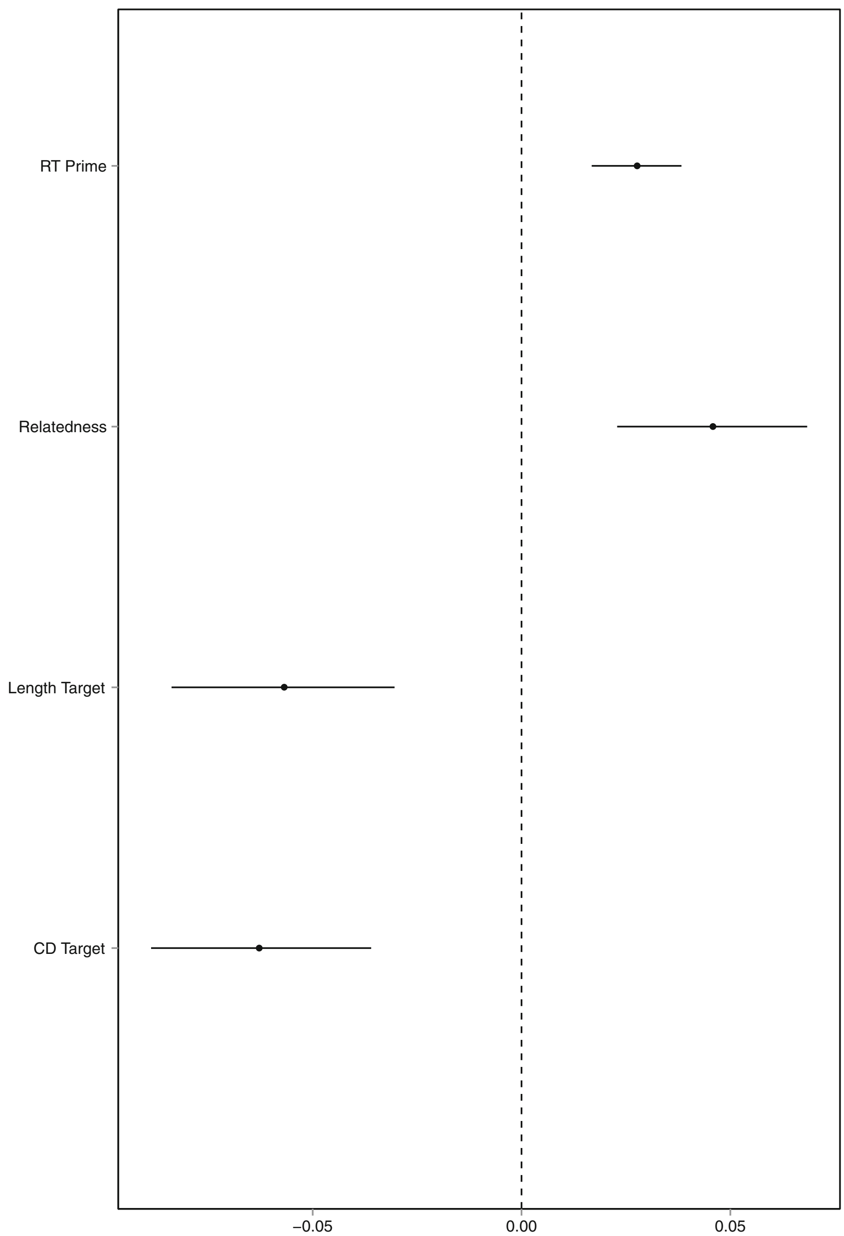

Fig. 1 95% highest posterior density intervals of the four regression weights. The dots represent the point estimates of the weights

prime–target pairs were category coordinates. Also, it is difficult to compare the present experiment, which is actually a five-alternative forced-choice task, with a lexical decision task, where there are only two response options (i.e., *word* or *nonword*). These issues were addressed in Experiment 2.

Experiment 2

In Experiment 2, the objective was to examine semantic priming using a two-alternative variant of the continuous speeded word fragment completion task, thereby making the paradigm comparable to a lexical decision task. To this end, word fragments were constructed in which the missing letter was always either an *a* or an *e*. The latter two letters were chosen because of their high frequency of occurence. In addition, we wanted to generalize to other types of prime–target associations, so besides category coordinates (e.g., *oyster–mussel*) we also included supraordinates (e.g., *beetle–insect*), property relations (e.g., *magpie–black*), script relations (e.g., *napkin–table*), and synonyms (e.g., *neat–clean*).

Method

Participants Participants were 40 first-year psychology students of the University of Leuven (3 men, 37 women, mean age 19 years), who participated in return for course credit. All participants were native Dutch speakers.

Materials A total of 72 related prime–target pairs were constructed (see Table 1 for item characteristics and Appendix B for all the pairs). Primes and targets were either category coordinates (N = 16), property relations (N = 16), script relations (N = 16), supraordinates (N = 8), or synonyms (N = 16). Prime–target pairs had a forward association strength that ranged from 3 % to 33 %. In addition, 72 unrelated filler pairs were constructed.

All word fragments were generated by omitting either the letter *a* or *e* from a Dutch noun, verb, or adjective. Only word fragments that had a unique correct response were used. Half of the primes, targets, and fillers required an *a* response, the other half an *e* response.

As in Experiment 1, two lists were created such that a random half of the 72 critical targets were preceded by their related prime in List A, whereas in List B they were preceded by an unrelated word, and vice versa. The 36 unrelated pairs for each list were constructed by randomly recombining primes and targets. In contrast to Experiment 1, where only a fraction of the related prime–target pairs were response congruent, here, half of the prime–target pairs were. This was to ensure that the response to the target could not be predicted based on the response to the prime. As in Experiment 1, the unrelated pairs were created in a way that they matched in terms of response congruency. When a related pair was response congruent/incongruent, so was the corresponding unrelated pair. For each prime–target pair, the missing letters could respectively be *a* and *a* (as in n_pkin–t_ble), *e* and *e* (as in beetl_–ins_ct), *e* and *a* (as in ov_n–pizz_), or *a* and *e* (as in pum_–tig_r). These four combinations were evenly represented in all five prime–target relations (i.e., coordinate, supraordinate, property, script, and synonym) and in the filler pairs.

Procedure

The procedure was the same as in Experiment 1, except that participants had only two response options instead of five. Also, the response buttons were now the arrow keys. Half of the participants had to press the left arrow for an *a* response and the right arrow for an *e* response, and vice versa for the other half. Before the experimental phase, participants performed 32 practice trials. The experiment was part of a series of unrelated experiments and took approximately 10 min.

Results and discussion

Again we first calculated the split-half reliability of the response times to the 72 critical targets. The reliabilities, averaged over the 10,000 randomizations of participants, were .87 for both List A and List B. For the log-transformed response times, the reliabilities were .87 and .89, respectively. One participant whose log-transformed response times did not correlate with the average log-transformed response times of all other participants (r = –0.05) was removed from the analysis.

Erroneously completed targets (4.2 % of the data) and targets preceded by an incorrectly completed prime were not included in the analysis (3.3 % of the data). Furthermore, responses faster than 250 ms and slower than 4,000 ms were removed, after which an individual cutoff value for each participant was computed as the mean response time plus 3 standard deviations. Response times exceeding this criterion were also excluded (resulting in the discarding of another 2.7 % of the data). This led to an average response time of 811 ms (SD = 311).

The log-transformed response times were fitted using the same model as in Experiment 1. The response times were predicted by four variables: Relatedness (i.e., whether the target is preceded by a related or unrelated prime), Contextual Diversity of the target, Word Length of the target, and the log-transformed response time to the prime (RT Prime). The latter three variables were again z-transformed. Furthermore, we included a random intercept for participants and items and by-item and by-participant random slopes of Relatedness.

Figure 2 shows the 95 % highest posterior density interval for the predictors. Again, they all have a HPD95 that excludes zero. Comparing Fig. 1 with Fig. 2, one can see that the results from both experiments look fairly similar. We found a

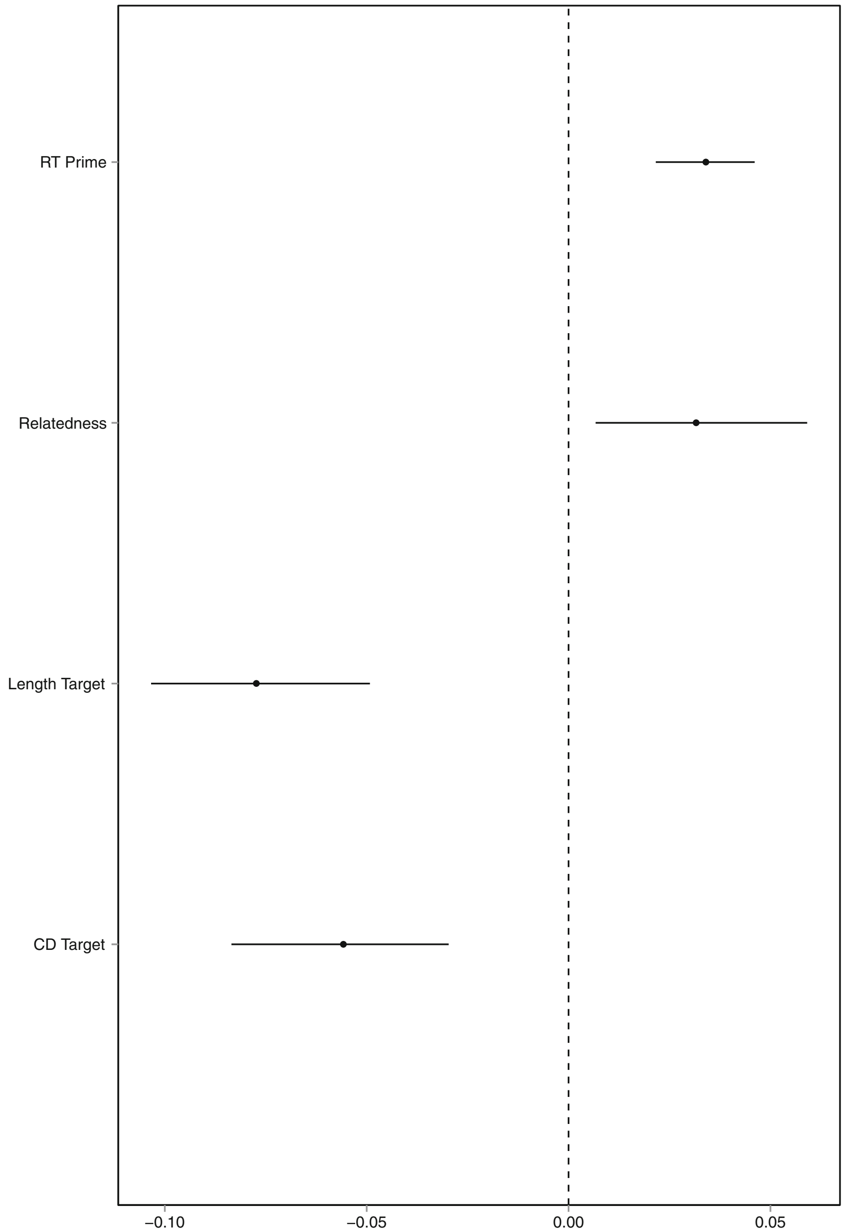

Fig. 2 95% highest posterior density intervals of the four regression weights. The dots represent the point estimates of the weights

significant priming effect (pMCMC = .02, $t = 2.21$, $p = .03$), but the magnitude appears to be somewhat smaller. Based on the point estimates of the fixed effects, we obtain a priming effect of 24 ms.

As in Experiment 1, we checked to see whether there was a priming effect in the untransformed response times as well. To this end, we fitted the response times using only Relatedness as a predictor. The random part of the model remained the same (i.e., random intercepts and random slopes of Relatedness). The results again showed a significant priming effect (pMCMC < .01, $t = 2.68$, $p < .01$). The magnitude as assessed by the point estimate of the regression weight was 35 ms.

To examine whether the priming effect differed over the five types of prime–target relations, two extra models were compared. For the first model, we started from the four predictors described above and added a fifth variable indicating the nature of the prime–target relation. The dependent variable was again the log-transformed response time. In addition to the main effect of relation type, the second model also comprised an interaction between the latter variable and Relatedness. If priming varied as a function of the prime–target relation, one would expect the second model to fit the data better. However, this was not the case according to goodness-of-fit measures (AIC = 613.4, BIC = 694.9 for the first model; AIC = 619.1, BIC = 723.8 for the second model). It should be noted, though, that targets from the five relation types were not matched on baseline response time or any other variable, for that matter. Also, the number of items per type is probably too low to warrant strong conclusions.

Overall, Experiment 2 replicates and extends the findings of Experiment 1 to other prime–target relations. Furthermore, it shows that a two-alternative forced-choice variant of the speeded word fragment completion task, which is similar in design to a lexical decision task, can also capture semantic priming effects. Hence, this task may prove a viable alternative for the lexical decision task to examine semantic priming. Note that the priming effect in Experiment 1 (i.e., 43 ms or 56 ms, depending on whether response times were log-transformed) was larger than the effect observed in Experiment 2. This is most likely driven by the higher difficulty level of Experiment 1, evident in the slower response times, which involved five response options in comparison with just two in Experiment 2. As a consequence, participants presumably relied more on the semantically related primes, thus boosting the priming effect. This is conceptually similar to the finding that visually degrading target words also increases priming effects (Balota et al., 2008).

So far we have established that, like the lexical decision task, the speeded word fragment completion task is sensitive to semantic priming. However, we are still agnostic about some of the differences and similarities between the two tasks. The goal of Experiment 3 was to address some pertinent questions: Is the magnitude of the priming effect different? Is the item-level priming effect stable across tasks or, in other words, do prime–target pairs that show a large priming effect in one task also exhibit strong priming in the other task? Are the priming effects equally reliable? To answer these questions, we basically replicated Experiment 2, but instead of asking participants to complete word fragments, they were shown the whole word and had to perform a continuous lexical decision task on exactly the same stimulus set used in Experiment 2.

Experiment 3

Method

Participants Participants were 40 students of the University of Leuven (10 men, 30 women, mean age 20 years), who participated in return for course credit or payment of €8. All participants were native Dutch speakers.

Materials A total of 576 pairs were used in a continuous lexical decision task: 144 word–word pairs, 144 word–pseudoword pairs, 144 pseudoword–word pairs, and 144 pseudoword–pseudoword pairs. The 144 word–word pairs were the same stimuli as those used in Experiment 2 except that they were presented in their complete form now rather than fragmented. Consequently, there were again two lists with 72 filler pairs and 72 critical prime–target pairs, of which half were related and half unrelated. The 576 pseudowords were created by Wuggy (Keuleers & Brysbaert, 2010), a pseudoword generator that obeys Dutch phonotactic constraints. The 576 words were used as input and Wuggy returned pseudowords with the same length and a similar subsyllabic structure and orthographic neighborhood density. This matching is important because research has shown that increasing the similarity between words and nonwords increases semantic influences on lexical decision performance (Joordens & Becker, 1997; Stone & Van Orden, 1993).

Procedure

The procedure was the same as in Experiment 2 except for the following changes. Participants were informed that they would see a letter string on each trial and that they had to indicate whether the letter string formed an existing Dutch word or not by pressing the arrow keys. Half of the participants had to press the left arrow for *word* and the right arrow for *nonword*, and vice versa for the other half. Because the experiment took about 20 min, the task was split into two blocks. After the first block, participants were allowed to take a break. The word pairs were randomly assigned to a block in such a way that every block contained an equal number of words and pseudowords. Also, the 36 related pairs were evenly divided over blocks and the order within blocks was random. The experiment was part of a series of unrelated experiments.

Results and discussion

The split-half reliabilities of the response times to the critical targets, averaged over the 10,000 randomizations of participants, were .42 for List A and .31 for List B. For the log-transformed response times, the reliabilities were .61 and .67, respectively. Two participants whose log-transformed response times did not correlate with the average log-transformed response times of all other participants ($r = 0.04$ and 0.06) were removed from the analysis in order to increase the overall reliability of the (log-transformed) response times. Note that these estimated reliabilities are considerably lower than those obtained in the speeded word fragment completion tasks of Experiments 1 and 2.

Error responses to targets (4.8 % of the data) and targets preceded by a misclassified prime were not included in the analysis (12.5 % of the data). Furthermore, responses faster than 250 ms and slower than 4,000 ms were removed, after which an individual cutoff value for each participant was computed as the mean response time plus 3 standard deviations. Response times exceeding this criterion were also excluded (resulting in the discarding of another 2.1 % of the data). This led to an average response time of 571 ms ($SD = 153$).

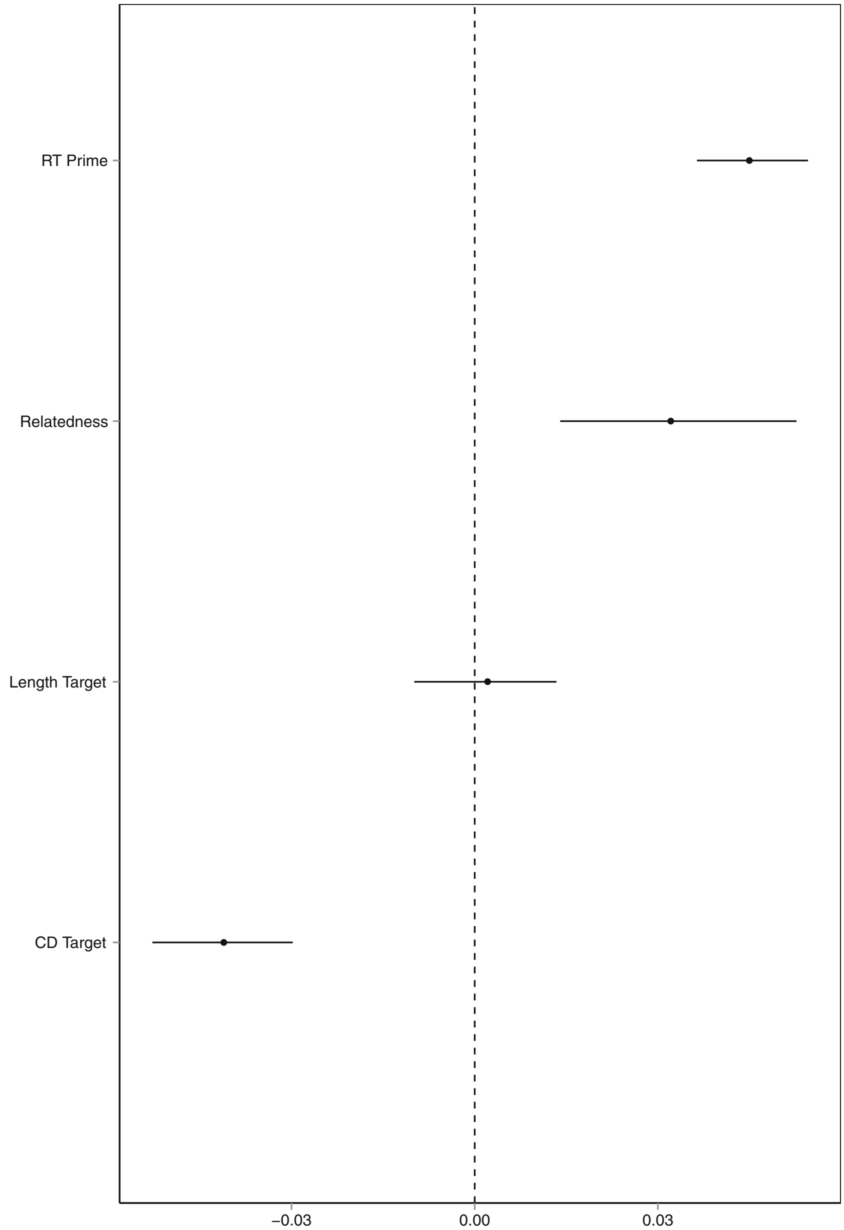

Fig. 3 95% highest posterior density intervals of the four regression weights. The dots represent the point estimates of the weights

The log-transformed response times were fitted using the same model as in Experiments 1 and 2. The results are shown in Fig. 3. Except for Length Target, all predictors have a HPD95 that excludes zero. As expected from previous studies using the continuous lexical decision task (see, e.g., McNamara & Altarriba, 1988; Shelton & Martin, 1992) we obtained a significant semantic priming effect (pMCMC < .01, $t = 3.22$, $p < .01$). The magnitude of the effect based on the point estimates of the regression coefficients is 18 ms, which is numerically a bit smaller than the 24-ms effect obtained in Experiment 2.

When looking at the results of the analysis on the untransformed response times with only Relatedness as a predictor and the same random structure as previous models, we see a similar pattern. That is, the priming effect differs significantly from zero (pMCMC < .001, $t = 3.30$, $p < .001$), but is again numerically smaller in terms of magnitude (i.e., the point estimates indicate an effect of 22 ms here vs. 35 ms in Experiment 2).

Comparison

In this section, we will evaluate the similarities and differences between the two tasks. The discussion will focus on four domains: reliability, error responses and response times, priming effect, and the predictors of response time.

Reliability

The reliability of the response times in the speeded word fragment completion task ranged from .87 (in Experiment 2) to .92 (in Experiment 1), which is very high for response times. For the lexical decision task, the reliability of the raw response times was rather poor (.31 and .42 for the two lists). The reliability of the log-transformed response times was better (.61 and .67) and in the range of estimates reported in the literature (Hutchison, Balota, Cortese, & Watson, 2008). However, the reliability of the speeded word fragment completion task is still much higher. Because the reliability of the log-transformed response times was far better than that of the raw response times, all further analyses are conducted on the transformed response times unless noted otherwise.

We also assessed the reliability of the priming effect. The priming effect per item for one random half of the participants [defined as mean log(RT) in the unrelated condition – mean log(RT) in the related condition] was correlated with the priming effect of the other half. This procedure was repeated for 10,000 randomizations of the participants. After applying the Spearman–Brown formula, the resulting reliabilities for Experiments 1, 2, and 3 were, respectively, .66, .35, and .39. The latter two are in line with what Hutchison et al. (2008) reported in a regular lexical decision task. The reliability of the priming effect in Experiment 1 is much higher though.

Taken together, the reliabilities of the response times are higher in the speeded word fragment completion tasks (Experiments 1 and 2) than in the lexical decision task (Experiment 3). The reliability of the priming effect, on the other hand, is only higher in the five-alternative forced-choice variant of the speeded word fragment completion task (Experiment 1). Note, however, that the prime–target pairs in Experiment 1 were different from those in Experiments 2 and 3, so we should be cautious when interpreting this higher reliability.

Errors and response times

Next, we compared the number of errors and the response times for both tasks. Because the task demands were rather different in Experiment 1, we focused only on Experiments 2 and 3. For the response time analysis, we pooled the data of Experiments 2 and 3 using primes, targets, and fillers. After removing outliers and error responses as described above, the log-transformed response times were fitted using a mixed-effects model with only one predictor, Experiment Version. This variable had two values to indicate the task (i.e., word fragment completion or lexical decision task), with the lexical decision task being the baseline. The random part of the model consisted of a random intercept for participants and items and by-item random slopes of Experiment Version. The results yield a significant positive effect of Experiment Version (pMCMC < .001, $t = 10.66$, $p < .001$), such that response times were longer in the speeded word fragment completion task than in the lexical decision task.

The analysis of the error responses was different in two respects. First, we obviously did not remove error responses or outliers. Second, the dependent variable is binary now; thus, the responses (i.e., correct or false) were fitted using a mixed-logit model with a similar structure as was described in the previous paragraph. The effect for Experiment Version was again significant ($Z = 4.44$, $p < .001$) meaning that participants made fewer errors in the fragment completion than in the lexical decision task.

In sum, participants in the lexical decision task are inclined to respond faster, which makes them more error prone than with the speeded word fragment completion task. Even though the instructions in both tasks were identical and stressed both speed and accuracy, participants seemed to adopt a different strategy. For instance, the word *sabre* (*sabel*, in Dutch) is classified as a nonword by 37 % of the participants, whereas it is correctly completed by all but 1 participant in the speeded word fragment completion task. The latter is taken to mean that participants know the word yet they often fail to recognize it in lexical decision, presumably because the speeded word fragment completion task requires a different focus.

Priming effect

Magnitude Based on the point estimates of the regression coefficients from Experiments 2 and 3, it appears that the priming effect is numerically larger in the speeded word fragment completion task (24 ms and 35 ms for, respectively, the log-transformed and raw response times) than in the lexical decision task (respectively, 18 ms and 22 ms). To evaluate whether the magnitude of the priming effect significantly differed from one task to the other, we again pooled the data from Experiments 2 and 3. Similar analyses as the ones described in the Results section of Experiments 2 and 3 were conducted. That is, we first fitted the log-transformed response times, but now two additional fixed effects were added. Besides Relatedness, CD Target, Length Target, and RT Prime, we also included a main effect of Experiment Version and an interaction between Relatedness and Experiment Version. If the priming effect were significantly larger in the speeded word fragment completion task, then it would be reflected in this interaction term. The results showed that the interaction term did not significantly differ from zero (pMCMC = .89, $t = 0.13$, $p = .90$).

Secondly, we looked at the untransformed response times and fitted a model with only Relatedness, Experiment Version, and an interaction between both variables. Again there was no evidence for an interaction (pMCMC = .37, $t = 0.94$, $p = .35$).[3] Similarly, the priming effect per participant (mean unrelated – mean related) was not significantly larger in the speeded word fragment completion task than in the lexical decision task [$t(75) = 0.95$, $p = .35$]. We can thus conclude that, although numerically larger, the magnitude of the priming effect is not significantly higher in the speeded word fragment completion task. Furthermore, if we take into account that a lexical decision requires less time (see above) and the fact that priming effects increase with baseline response time (Hutchison et al., 2008), it is to be expected that the priming effect in the lexical decision task is somewhat smaller. To attest this, we transformed the response times for each participant into z-scores, thereby controlling for task differences in baseline response times. Now, the priming effect was numerically somewhat larger in the lexical decision task, but again the difference was not significant, as evidenced by an analysis of the priming effect per participant [$t(75) = -0.88$, $p = .38$].

Item level In this section we examine whether the priming effect per item in one task is related to the priming effect of the item in the other task. So suppose that *napkin–table* shows a small priming effect in the lexical decision task and *puma–tiger* a large effect. We will assess if these item differences are conserved in the speeded word fragment completion task. To this end, the item-level priming effect, defined as mean log(RT) of the item in the unrelated condition – mean log(RT) of the item in the related condition, was calculated for both tasks separately. Next, the priming effect for each item in the lexical decision task was correlated with the corresponding priming effect in the speeded word fragment completion task (see Fig. 4). Interestingly, there appears to be no correlation between the priming effects obtained from both tasks [$r(70) = -.03$, $p = .80$].[4] Even though both tasks do find semantic priming, the item-level effects from one task do not generalize to the other task. Further inspection suggests that (part of) this discrepancy is due to variability in baseline response times. Figure 5 shows the average response time in the unrelated condition for every item in the lexical decision task (y-axis) and in the speeded word fragment completion task (x-axis). Items that are recognized faster in the lexical decision task are generally also

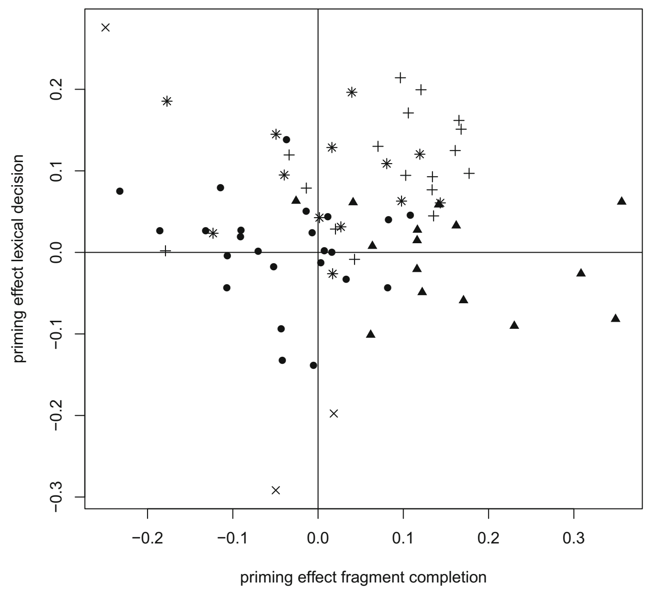

Fig. 4 Priming effect per item in the speeded word fragment completion task plotted against the priming effect per item in the lexical decision task. Every symbol represents an item. The plus sign (+) represents items that require more time than average in both tasks, the dots show the items that take less time than average in both tasks, the star sign (*) represents items completed more quickly than average in the speeded word fragment completion task, but recognized more slowly than average in the lexical decision task, and vice versa for the triangles. The × sign represents items that were not recognized as words by more than 10 participants

completed faster in the speeded word fragment completion task [$r(70) = .26$, $p = .03$]. Although significant, this correlation is far from perfect, as is evident from Fig. 5.[5] Now, the lack of consistency across tasks in the item-level priming effects is (primarily) driven by these varying baseline response times. This is illustrated in Figs. 4 and 5 by the different symbols. The plus sign (+) represents items that require more time than average in both tasks (see Fig. 5), whereas the dots are the items that take less time than average in both tasks. Items completed faster than average in the speeded word fragment completion task, but recognized more slowly than average in the lexical decision task, are depicted by the star sign (*), and vice versa for the items represented by a triangle. Finally, three items that were considered to be outliers because they were categorized as nonwords by more than 10 participants are symbolized by the × sign.

With this symbol scheme in mind, a rather clear pattern emerges from Fig. 4. Items with an above-average response time in both tasks (i.e., denoted by the + sign) tend to show a consistent priming effect across tasks, as they are mostly located in the upper right quadrant of Fig. 4. For items requiring more time than average in the speeded word fragment completion task, but less time in the lexical decision task (i.e., the triangles), we obtain large priming effects in the speeded

[3] Note that there were five different types of prime–target relations (i.e., coordinates, supraordinates, property relations, script relations, and synonyms). When repeating the analyses for every type separately, there was never evidence for a Relatedness × Experiment Version interaction (all ps > .15). However, we should point out that the number of items per type may have been too limited to discern differences between tasks in this respect.

[4] Because one cannot rely on frequentist statistics to quantify support for the null hypothesis, a default Bayesian hypothesis test for correlations was performed (Wetzels & Wagenmakers, 2012). The analysis yielded a Bayes factor of 0.096, which is, according to Jeffreys' classification (1961), strong evidence for the null hypothesis (i.e., the correlation is zero).

[5] Even if we apply Spearman's correction for attenuation formula (1904) to take measurement error into account, the correlation maximally increases to .36.

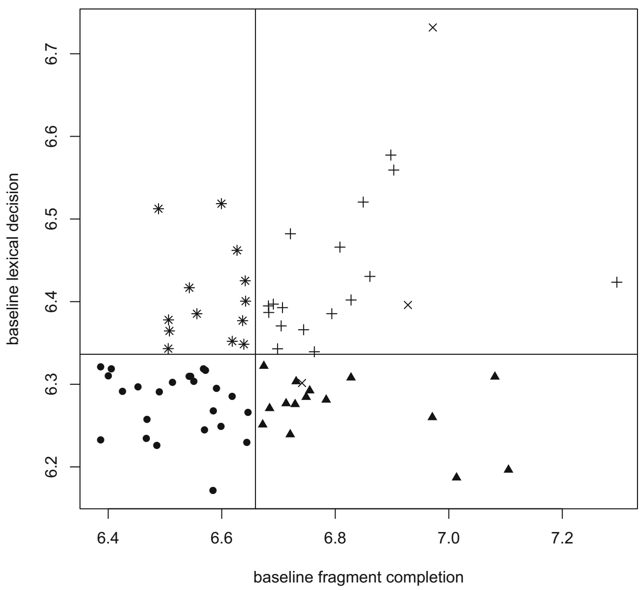

Fig. 5 Average log-transformed response time in the unrelated condition for every item in the speeded word fragment completion task and the lexical decision task. Every symbol represents an item. The black lines indicate the grand average for each respective task, thereby creating quadrants. Items get a different symbol depending on their position in those quadrants

word fragment completion task and no (or very small) effects in the lexical decision task. The reverse is true for items with a relatively high baseline response time in the lexical decision task and a low baseline response time in the speeded word fragment completion task (i.e., denoted by the * sign): Small or no priming effects in the speeded word fragment completion task and mostly large priming effects in the lexical decision task were observed. Finally, the items that take less time than average in both tasks (i.e., the dots) are somewhat scattered across the figure. But in general, these items show no or even a somewhat negative priming effect in both tasks.

Taken together, Figs. 4 and 5 suggest the following. The higher the baseline response time of an item, the larger its priming effect (see also Hutchison et al., 2008). Because baseline response times are far from perfectly correlated across tasks, there is little consistency in priming effects over tasks. To test this hypothesis, we again fitted the log-transformed response times of the pooled data from Experiments 2 and 3. A similar mixed-effects model was used as the one in the previous section about the magnitude of the priming effect. However, besides the three covariates CD Target, Length Target, and RT Prime, the following crucial predictors were added: Relatedness, Experiment Version, Lex Baseline (i.e., the baseline log-transformed response times of the items in the lexical decision task), and Frag Baseline (i.e., the baseline log-transformed response times of the items in the speeded word fragment completion task). In addition to the main effects, we also included seven interaction terms: Relatedness × Experiment Version, Relatedness × Lex Baseline, Relatedness × Frag Baseline, Experiment Version × Lex Baseline, Experiment Version × Frag Baseline, Relatedness × Experiment Version × Lex Baseline, and Relatedness × Experiment Version × Frag Baseline.

The results show that the priming effect in the lexical decision task indeed significantly increases with baseline response time of the item in the lexical decision task (i.e., Relatedness × Lex Baseline is significantly larger than zero, pMCMC < .001, $t = 5.45$, $p < .001$), but not with baseline response time of the item in the speeded word fragment completion task (i.e., Relatedness × Frag Baseline is not significantly larger than zero; in fact it is numerically smaller than zero, pMCMC = .24, $t = -1.18$, $p = .24$). For the speeded word fragment completion task, we obtain a reverse pattern: The priming effect increases with baseline response time of the item in the speeded word fragment completion task (pMCMC < .001, $t = 8.00$, $p < .001$). Interestingly though, the priming effect also increases if the baseline response time of the item in the lexical decision task *decreases* (pMCMC < .01, $t = -2.91$, $p < .01$). This was already apparent in Fig. 4. The largest priming effects in the speeded word fragment completion task were obtained for short, high-frequency words such as *money* (*geld*, in Dutch), *work* (*werk*, in Dutch), and *warm*, which are easily recognized as words in a lexical decision task (i.e., the three triangles located on the right-hand side of Fig. 4). It is an attractive quality of the speeded word fragment completion task that it can capture semantic priming in such instances, because the lexical decision task failed to find a priming effect for those items.[6] This is especially relevant if we consider the centrality of concepts such as *warm*, *work*, and *money* in a word association network. PageRank, a commonly used measure to express this centrality (see Griffiths, Steyvers, & Firl, 2007), was calculated for over 12,000 words in the association database. The ranks for these examples, *warm* (6), *work* (33), and *money* (8), confirm that these words are among the most central in the network. Questions pertaining to the relation between associative strength and semantic priming can never be fully resolved if short, high-frequency words are not considered because potential priming effects are undetectable with a lexical decision task. Instead, one might use the speeded word fragment completion task as a viable alternative.

In a final analysis, we examined whether forward association strength was correlated with the item-level priming effects and whether the relation differed between the two tasks. To this end, a multiple regression analysis was run with the item-level priming effect as dependent variable. Three predictors were included: Forward Association Strength (based on three associations per cue metric; this variable was *z*-transformed), Task (the speeded word fragment completion task vs.

[6] The latter is not surprising, given the finding that priming in the lexical decision task decreases when word frequency increases (Becker, 1979).

the lexical decision task) and a Forward Association Strength × Task interaction. The results revealed no significant main effects, but the interaction did reach significance [$t(140) = 2.01$, $p = .05$]. A follow-up analysis showed that the correlation between forward strength and priming was numerically positive for the speeded word fragment completion task ($r = .17$), but negative for the lexical decision task ($r = –.17$), though neither correlation differed significantly from zero [respectively, $t(70) = 1.40$, $p = .16$ and $t(70) = –1.47$, $p = .15$].[7] The latter negatively signed correlation is somewhat puzzling; however, it should be noted that the items were not selected to match on baseline response time. As shown by Hutchison and colleagues (2008) and demonstrated by the analyses reported above, baseline response times determine to a large extent the magnitude of the priming effect, and strong associates tend to be higher-frequency words that have faster baseline response times in lexical decision. Hence, the present results should be interpreted with caution. Further research pairing the same targets with different primes that vary in associative strength to the targets (e.g., thunder–lightning, flash–lightning,…) could shed more light on this issue.

Predictors of responses times

The previous section showed that the item-level priming effects correlate with baseline response time. However, so far we have not considered predictors of baseline response time. In this section, we will explore what variables are related to the response times in the speeded word fragment completion task and then compare them with those related to the response times in the lexical decision task.

First, we selected three predictors from the literature about word recognition: contextual diversity (CD Word), length in characters (Length Word), and number of orthographic neighbors at a Hamming distance of 1 (Neighbors Word). The latter variable indicates for every word the number of existing words that can be formed by substituting one letter. This measure was obtained via the vwr R package (Keuleers, 2011) using words that occurred more than once in the SUBTLEX-NL database (Keuleers, Brysbaert, & New, 2010) as lexicon. Two additional predictors, Sort and Neighbors Distractor, were derived based on the nature of the speeded word fragment completion tasks. The variable Sort indicates whether or not the omitted vowel is part of a double vowel. In the fragment m_tro (to be completed as *metro*), for instance, the missing letter is a single vowel, whereas in ne_ron (to be completed as *neuron*) it is part of a double vowel. The predictor Neighbors Distractor quantifies the orthographic neighbors of the distractors at Hamming distance 1. A distractor is here defined as a word fragment being completed with an incorrect letter. The distractors for, say, lett_ce are thus *lettace*, *lettece*, *lettice*, and *lettoce*. The operationalization of Neighbors Distractor differs from Experiment 1 (i.e., a five-alternative forced-choice task) to Experiment 2 (i.e., a two-alternative forced-choice task), because there are four distractors for every word in Experiment 1, whereas there is only one distractor per word in Experiment 2. Therefore, Neighbors Distractor in Experiment 1 was defined as the number of orthographic neighbors at Hamming distance 1 averaged across the four distractors (e.g., the neighbors of *lettace* + *lettece* + *lettice* + *lettoce* divided by 4). In Experiment 2, Neighbors Distractor was simply the number of neighbors of the one distractor (e.g., for tig_r, it is the number of neighbors of *tigar*). Due to such task differences, the data from different experiments were analyzed separately.

Thus, the five variables described above (i.e., CD Word, Length Word, Neighbors Word, Sort, and Neighbors Distractor) were used to predict the log-transformed response times obtained from Experiments 1, 2, and 3. Neighbors Word and Neighbors Distractor were log-transformed, and all variables except Sort were then *z*-transformed to facilitate interpretation. In order to have a large sample, we included not only the 76 or 72 critical targets, but also the primes and filler items. Before the actual analysis, we employed a similar data-cleaning procedure as was explained in the Results section of Experiments 1, 2, and 3, except that trials were not removed if an error was made on the preceding trial. This was done because we are no longer investigating priming effects, for which it was crucial that primes are correctly identified.

The log-transformed response times were then fitted using a somewhat different model than the one used thus far. The fixed effects part is rather straightforward: the five predictors plus an intercept. The random effect structure now contains a random intercept for participants and items and by-participants random slopes of CD Word, Length Word, Neighbors Word, Sort, and Neighbors Distractor. The reason for the random slopes is that those five variables are not control variables, as some of them were in the analyses reported above. Instead, the goal here is to make inferences about them. In such cases, Barr et al. (2013) recommend including random slopes in the model.

Figure 6 shows the results for Experiment 1. It depicts the 95 % highest posterior density interval for the five predictors. As was already apparent in Figs. 1 and 2, contextual diversity is related to the speed with which word fragments are completed (pMCMC < .001, $t = –7.08$, $p < .001$). That is, words appearing in many different contexts are completed more quickly. Word length seems to be unrelated to response time (pMCMC = .71, $t = 0.35$, $p = .73$). This is a somewhat surprising finding, because Figs. 1 and 2 seemed to suggest a negative relation between word length and response time

[7] Both correlations increased to, respectively, .21 and –.22, and became marginally significant if Forward Association Strength was calculated considering only primary associates.

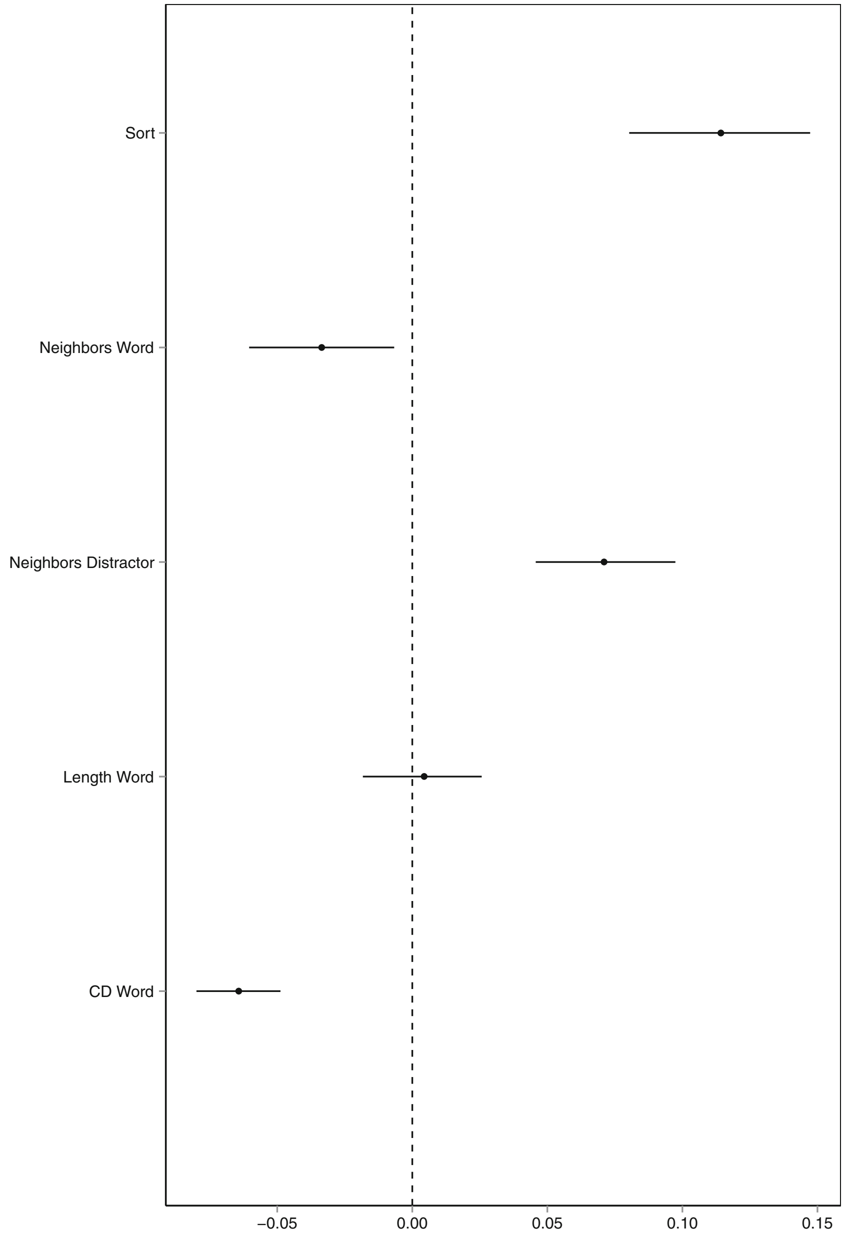

Fig. 6 95% highest posterior density intervals of the five regression weights for the data from Experiment 1. The dots represent the point estimates of the weights

(i.e., higher response times for shorter words). The superficial discrepancy is caused by the addition of the three extra predictors to the model (i.e., Sort, Neighbors Word, and Neighbors Distractor). If we were to remove those variables, we again obtain a significant length effect (pMCMC < .001, t = –3.77, p < .001). In other words, the length effect is probably spurious, because it disappears when controlling for Sort, Neighbors Word, and Neighbors Distractor.

Turning to Neighbors Word and Neighbors Distractor, we see that both are significantly related to response times (pMCMC = .02, t = –2.15, p = .03 and pMCMC < .001, t = 4.82, p < .001, respectively). Specifically, words with many orthographic neighbors are completed faster, whereas word fragments for which the distractors have many neighbors are completed more slowly. To illustrate the latter, consider the fragment f_lm (to be completed as *film*). Here, the distractors are *falm*, *felm*, *fulm*, and *folm*, which have many orthographic neighbors (e.g., for *falm*: *calm*, *palm*, *farm*, *fall*,…). This, in turn, seems to hamper the word fragment completion, as evidenced by the longer response times. It may also explain the ostensible relation between word length and response time observed in Figs. 1 and 2, because short words tend to have distractors with many orthographic neighbors. Finally, response times were higher if the omitted letter was part of a double vowel (i.e., the variable Sort, pMCMC < .001, t = 5.99, p < .001).

We now turn to Experiment 2, for which the same analysis was conducted except that the variable Sort was not included because the missing vowels were never part of a double vowel in this experiment. The results are presented in Fig. 7. We can see a similar relation between contextual diversity and response time as in Experiment 1 (pMCMC < .001, $t = -8.70$, $p < .001$). Furthermore, there was again no evidence for an effect of word length (pMCMC = .86, $t = -0.15$, $p = .88$). Quite surprisingly, and in contrast to Experiment 1, we found a positive relation between Neighbors Word and response time (pMCMC = .02, $t = 2.13$, $p = .03$). So, the more orthographic neighbors a word has, the more slowly the fragment is completed. A possible explanation may be that the items used in Experiment 2 are mostly short words with a relatively dense orthographic neighborhood, whereas the items of Experiment 1 were more diverse in that respect. This restriction in range may underlie the positive relation between Neighbors Word and response time. Evidence for this hypothesis comes from the results from the Dutch Lexicon Project, a large-scale study using the lexical decision task (Keuleers, Diependaele, & Brysbaert, 2010), which suggest that response times first decrease a bit and then increase as orthographic neighborhood size shrinks (Fig. 2, right panel, in Keuleers, Diependaele, & Brysbaert, 2010).

For the variable Neighbors Distractor, we find an analogous relation with response time as in Experiment 1: The time to complete a word fragment increases with the number of neighbors of the distractor (pMCMC < .001, $t = 5.02$, $p < .001$). This finding can also explain why we obtained the largest priming effects for words such as *work* (w_rk, to be completed as *werk* in Dutch), *money* (g_ld, to be completed as *geld*), and *warm* (w_rm, to be completed as *warm*). The distractors of these words (i.e., *wark*, *gald*, and *werm*) all have many orthographic neighbors in Dutch; hence, their baseline response time will be high. As a result, the priming effect will also be large (see above). This hypothesis was confirmed in two additional analyses similar to the ones described in the Results section of Experiments 1 and 2. The log-transformed response times to the targets were again predicted by Relatedness, CD Target, Length Target, and RT Prime, but now we also added the main effects of Neighbors Word and Neighbors Distractor and, crucially, an interaction of those variables with Relatedness. The results revealed a significant interaction between Neighbors Distractor and Relatedness in both Experiment 1 (pMCMC < .01, $t = 3.27$, $p < .01$) and Experiment 2 (pMCMC < .001, $t = 4.45$, $p < .001$). In other words, the priming effect increases if the distractors have many orthographic neighbors.

Based on the results from Experiments 1 and 2, one can derive some predictions about the magnitude of the item-level priming effects. Moreover, one can identify the items for which priming effects will be hard or virtually impossible to detect due to the low baseline response times. The latter are words with a high contextual diversity and with distractors that have few orthographic neighbors. Crucially, the speeded word fragment completion task is flexible, because one can in principle influence baseline response times by omitting a particular letter and/or selecting certain distractors. In our experiments, we kept the response options constant (*a*, *e*, *u*, *i*, and *o* in Experiment 1; *a* and *e* in Experiment 2), but this is not a necessity. One can opt to vary the response options over blocks or even on a trial-by-trial basis, which makes it possible to manipulate baseline response time and thus influence the magnitude of the priming effect.

To compare the speeded word fragment completion task with the lexical decision task, we analyzed the data from Experiment 3 using the same model as the one for Experiment 2. Although Neighbors Distractor makes no sense in the lexical decision task, we nevertheless included this predictor as a divergent validity check. To be able to relate the results from Experiments 2 and 3, we did not include all filler items in the analysis, only the ones that were also administered in Experiment 2 (N = 288).

Figure 8 shows the results. As expected (Adelman, Brown, & Quesada, 2006; Brysbaert & New, 2009), contextual diversity is negatively related to response time (pMCMC < .001, $t = -11.41$, $p < .001$). Word length, on the other hand, appears to be unrelated to response time (pMCMC = .81, $t = 0.21$, $p = .83$). In contrast to Experiment 2, there was no significant positive relation between response time and Neighbors Word (pMCMC =.10, $t = 1.62$, p = .11). Critically, we did not find a relation between Neighbors Distractor and response times (pMCMC = .79, $t = 0.25$, $p = .80$). This suggests that the variable Neighbors Distractor is not associated with word recognition in general, but that it plays a specific role in the speeded word fragment completion task.

In sum, contextual diversity and word length play a comparable role in fragment completion and word recognition: Contextual diversity was negatively related to response time, whereas word length was not predictive for response time. The influence of orthographic neighborhood size of the words is somewhat ambiguous; hence, we are hesitant to draw strong conclusions about this variable. With regard to the neighborhood size of the distractors, the picture is more clear-cut. Neighbors Distractors is positively related to response times in the speeded word fragment completion task, but not in the lexical decision task.

In a fourth and final experiment, we implemented this knowledge to test whether the speeded word fragment completion task is indeed more sensitive in detecting priming effects for short words that are central to people's associative network. To this end, 40 highly frequent 3- to 6-letter words were selected such that their corresponding distractors have a dense orthographic neighborhood. As suggested by Fig. 4, one might expect a strong priming effect for these items in the speeded word fragment completion task, whereas it might be harder to obtain a significant effect using the lexical decision

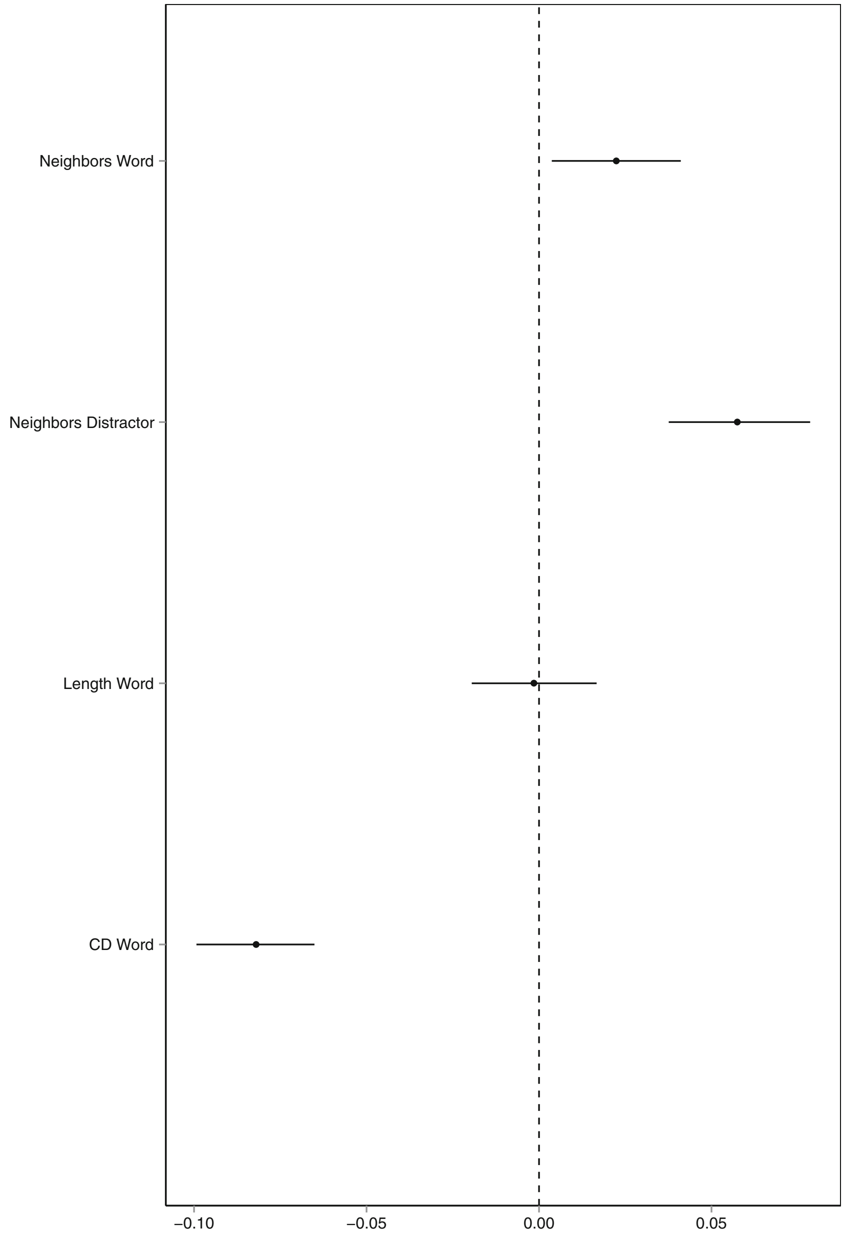

Fig. 7 95% highest posterior density intervals of the four regression weights for the data from Experiment 2. The dots represent the point estimates of the weights

task. In contrast to the previous experiments, participants were now asked to perform both tasks, which allows for a more straightforward comparison.

Experiment 4

Method

Participants Participants were 32 first-year psychology students of the University of Leuven (6 men, 26 women, mean age 19 years), who participated in return for course credit. All participants were native Dutch speakers.

Materials Forty prime–target pairs were constructed in the same fashion as in Experiments 2 and 3 (see Table 1 for item characteristics and Appendix C for all the items). That is, word fragments were generated by deleting the letter *a* or *e* from a Dutch word. There was always only one correct response. In half of the fragments, the letter *a* was omitted; in the other half, the letter *e*. The difference from the previous experiments was that the targets had to be short, highly frequent words with distractors that have many orthographic neighbors.

The experiment consisted of two blocks: one in which participants conducted a speeded word fragment completion task and one in which they did a lexical decision task. Depending on the task in which the items featured, they were either presented in

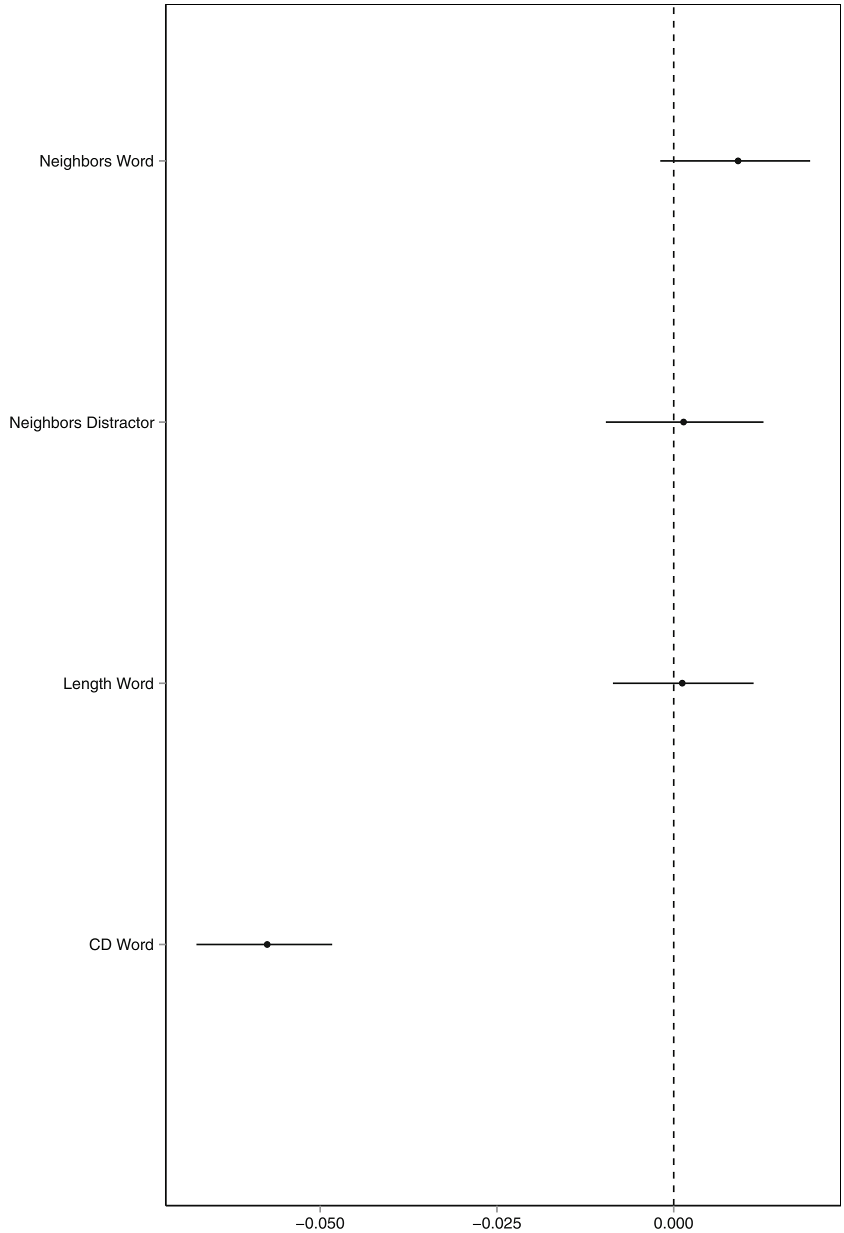

Fig. 8 95% highest posterior density intervals of the four regression weights for the data from Experiment 3. The dots represent the point estimates of the weights

their fragmented form (i.e., in the speeded word fragment completion task) or in their regular, unfragmented form (i.e., in the lexical decision task). As was the case in Experiments 2 and 3, the 40 critical prime–target pairs had a forward association strength that ranged from 3 % to 33 %. In addition, 40 unrelated filler pairs were constructed. The 40 critical targets were randomly divided into four lists, which defined whether they would be preceded by their related prime or not and whether they would be presented in the speeded word fragment completion block or in the lexical decision block. Again, the unrelated pairs were constructed by recombining primes and targets within a list, such that the response congruency of the prime and target matched that of the related pair. The latter naturally holds only for the word fragment completion task (see the Materials section of Experiments 1 and 2 for more details). The 40 word–word pairs of the lexical decision block (20 critical pairs + 20 filler pairs) were always supplemented by 40 word–pseudoword pairs, 40 pseudoword–word pairs and 40 pseudoword–pseudoword pairs. The pseudowords were created with Wuggy (Keuleers & Brysbaert, 2010), using the word stimuli as input.

Procedure

The experiment was split into two blocks. In one block, participants performed the speeded word fragment completion task as described in Experiment 2; in the other block, they performed the lexical decision task as described in Experiment 3. The order of the blocks was counterbalanced over participants. All items were shown only once, so either the word fragment, in the speeded word fragment completion block, or the full word, in the lexical decision block, was presented. Each block was preceded by 16 unrelated practice trials, and participants were given a break between the two blocks. As in Experiments 2 and 3, the response buttons were the arrow keys. This led to four combinations, which were also counterbalanced over participants: *a/word* left arrow and *e/nonword* right arrow; *e/word* left arrow and *a/nonword* right arrow; *a/nonword* left arrow and *e/word* right arrow; *e/nonword* left arrow and *a/word* right arrow. Altogether, this amounts to 32 versions of the experiment: order (lexical decision first vs. speeded word fragment completion first) × response keys word fragment completion (*a* left arrow vs. *e* left arrow) × response keys lexical decision (*word* left arrow vs. *nonword* left arrow) × relatedness (target preceded by related prime vs. unrelated prime) × task (target presented in the lexical decision block vs. the word fragment block).

After the actual experiment, participants were given a brief questionnaire to gauge their attitudes toward both tasks. They were asked on a five-point scale how annoying and how difficult they found each task, and also, which task they would prefer if they had to perform one for an hour. The entire experiment took approximately 15 min and was part of a series of unrelated experiments.

Results and discussion

Error responses to targets (3.0 % of the data) and primes (4.7 %) were discarded from the analysis, as were outliers (another 6.3 %). The latter was accomplished by first removing times below 250 ms and above 4,000 ms and then calculating a cutoff value per participant and per task. Response times exceeding this cutoff were also excluded. The average response time of the remaining data was 869 ms ($SD = 356$) in the fragment completion block and 579 ms ($SD = 112$) in the lexical decision block.

As in the previous experiments, the log-transformed response times were fitted using a mixed-effects model. The only difference was that besides the three covariates (i.e., CD Target, Length Target, and RT Prime) and the critical variable Relatedness, two additional fixed effects were added. That is, the main effect of task (i.e., Task) and the interaction between Task and Relatedness were now also included in the model. The random part again included random participant and item intercepts and by-item and by-participant random slopes of Relatedness.

Figure 9 summarizes the results. It shows that there is a significant main effect of Relatedness, in that targets preceded by a related prime are responded to more quickly than when they are preceded by an unrelated prime (pMCMC < .01, $t = 3.42$, $p < .001$). However, this priming effect interacts with Task (pMCMC = .04, $t = 2.06$, $p = .04$). Follow-up analyses examining the simple main effects reveal that there is a significant priming effect in the speeded word fragment completion task (pMCMC < .001, $t = 4.02$, $p < .001$), but not in the lexical decision task (pMCMC = .22, $t = 1.26$, $p = .21$). The magnitude of the effect, based on the point estimates, was, respectively, 73 ms and 17 ms.

Similar results were obtained in an analysis of the untransformed response times using the same random structure, but with only Relatedness, Task, and a Relatedness × Task interaction as fixed effects. That is, there was a significant main effect of Relatedness (pMCMC < .01, $t = 2.81$, $p < .01$) and a significant Relatedness × Task interaction (pMCMC = .02, $t = 2.33$, $p = .02$). Further inspection of the priming effects per task again showed a strong effect in the speeded word fragment completion task (pMCMC < .001, $t = 3.73$, $p < .001$), but no significant effect in the lexical decision task (pMCMC = .47, $t = 0.74$, $p = .46$). The priming effect derived from the point estimates was 87 ms in the speeded word fragment completion task and 18 ms in the lexical decision task. These findings confirm that the speeded word fragment completion task can uncover priming effects that may go undetected in a lexical decision task. This should not be taken to mean that the lexical decision task cannot find priming for high-frequency, short words. Rather, it may be less sensitive to finding (large) priming effects in those instances than is the speeded word fragment completion task. Conversely, as suggested by Fig. 4, the lexical decision task might more readily discover priming effects in longer words. In a way, both tasks seem to complement one another in this respect.

After completing the experiment, participants were asked to give their opinion about the two tasks by filling out a short questionnaire. Three participants did not finish the questionnaire and were excluded from this analysis. The results showed that the lexical decision task was perceived to be more annoying than the speeded word fragment completion task [$t(28) = 4.53$, $p < .001$]. Furthermore, it was judged to be more difficult, as well [$t(28) = 2.70$, $p = .01$]. Note, though, that the lexical decision block took longer to complete because it comprised 120 additional prime–target pairs in comparison with the speeded word fragment completion block (i.e., the pseudoword fillers). In an attempt to correct for this difference in duration, we also asked participants which task they would favor if they had to choose one to do for an hour-long experiment. Out of 29 participants, 26 preferred the speeded word fragment completion task, whereas only 3 opted for the lexical decision task. So about 90 % of the participants would choose the speeded word fragment completion task, which is

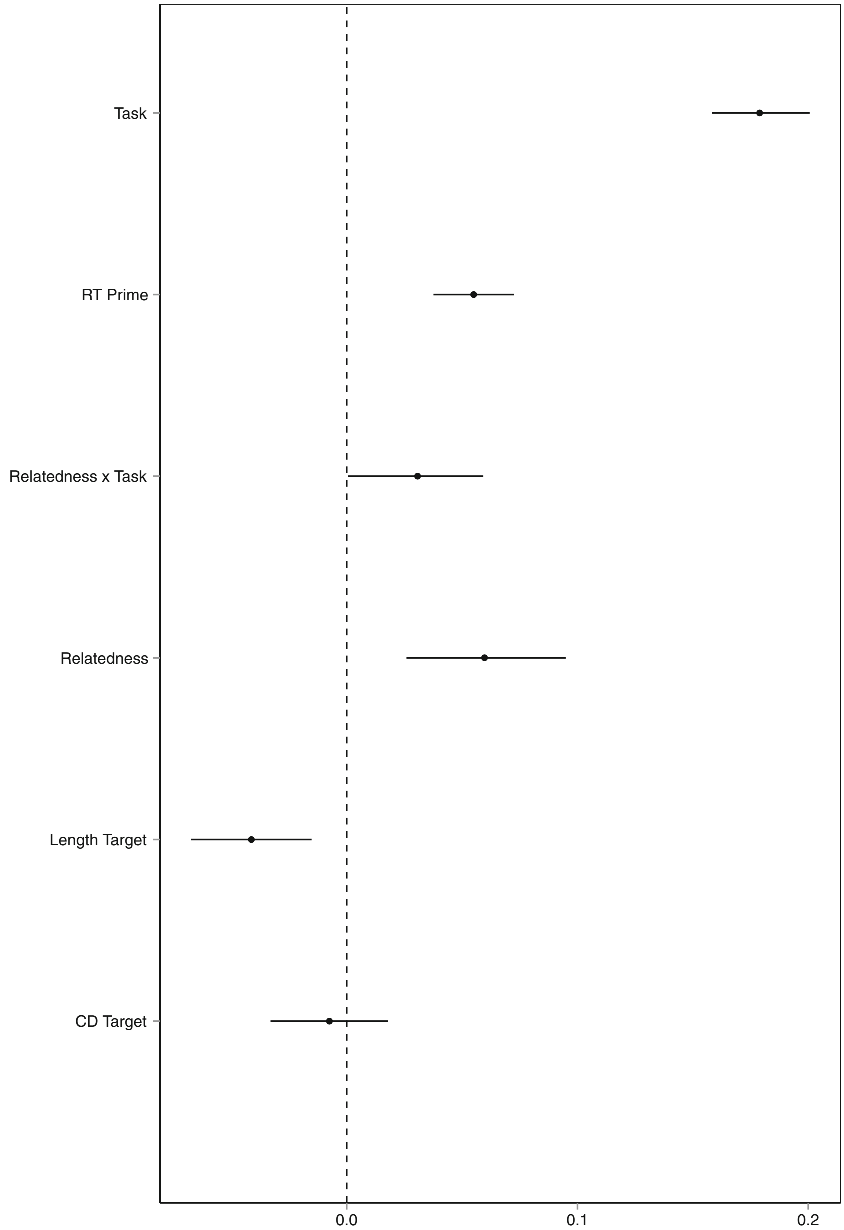

Fig. 9 95% highest posterior density intervals of the six regression weights. The dots represent the point estimates of the weights

significantly different from chance level [i.e., 50 %; $X^2(1) = 16.69$, $p < .001$].

In sum, the speeded word fragment completion task has been shown to capture priming effects for short, highly frequent words that play a central role in people's associative network. The lexical decision task, on the other hand, did not yield a significant priming effect for the same set of stimulus words. Furthermore, the speeded word fragment completion task is conceived to be more engaging and easier. In addition, if given the choice, participants would rather spend an hour doing the speeded word fragment completion task than the lexical decision task.

General discussion

Throughout the years, the lexical decision task has established itself as one of the most influential paradigms in (cognitive) psychology. To illustrate its popularity, according to ISI web of knowledge, over 550 articles featured the words *lexical decision* in their title. Despite the plethora of research, it has been proven rather difficult to draw unequivocal conclusions regarding the structure of the mental lexicon. The present research proposes a different method—that is, the speeded word fragment completion task—to examine semantic priming. In this task, participants are shown words from which one letter is omitted. Participants have to fill in the missing letter as fast as possible. Word fragments were selected such that there was only one correct completion possible, thereby making the task conceptually comparable to the lexical decision task.

Experiment 1 demonstrated that the speeded word fragment completion task can capture semantic priming for associatively related category coordinates using a five-alternative forced-choice design. Experiment 2 replicated and generalized this finding using also supraordinates, synonyms, property relations, and script relations in a two-alternative forced-choice format. Concretely, we obtained a priming effect of 43 ms and 24 ms in, respectively, Experiments 1 and 2, if log-transformed response times were used. Raw response times yielded priming effects of 56 ms and 35 ms, respectively. It is very unlikely that these are strategic priming effects because (A) the continuous nature of the task decouples primes and targets and (B) correct target responding is independent of any prime–target relation. Participants are confronted with a continuous stream of stimuli, which makes it difficult to adopt a predictive strategy such as expectancy generation. Furthermore, the relatedness proportion (i.e., the number of related pairs divided by the total number of pairs) in both studies was rather low (i.e., .125).[8] It is known that relatedness proportion is associated with conscious expectancy generation (Hutchison, 2007; Neely, 1977). People are less likely to generate a set of candidate targets, semantically related to the previously presented word, when the proportion of associated prime–target pairs is low. In addition, the correct response to a target in the speeded word fragment completion task is completely independent from its relation with the preceding prime. This renders a retrospective semantic matching strategy (i.e., checking whether prime and target are related) ineffective and thus presumably less prevalent. In sum, the employed methodology greatly reduces strategic priming effects, although it is theoretically possible that (some) participants engaged in expectancy generation even despite the low relatedness proportion. To further disentangle automatic and strategic processes, one might use a standard speeded word fragment completion task with a short stimulus onset asynchrony. In this paradigm, a briefly presented complete prime word is quickly replaced by a to-be-completed target. The short interval prevents expectancy generation (but not retrospective matching in a lexical decision task; see, e.g., Shelton and Martin, 1992), while the speeded word fragment completion task discourages retrospective matching.

To compare the speeded word fragment completion task with the lexical decision task, we conducted a third experiment, which was a replication of Experiment 2 using lexical decision. The results revealed several commonalities with the speeded word fragment completion task, but also some striking differences (see Table 2). First of all, the response times in the speeded word fragment completion task were more reliable. The reliability of the priming effect itself was higher in Experiment 1, though similar in Experiments 2 and 3. Secondly, participants were slower, but more accurate, in the speeded word fragment completion task.

Regarding the priming effect, we can conclude that the magnitude of the effect was similar (24 ms/35 ms in the speeded word fragment completion task, 18 ms/22 ms in the lexical decision task, depending on whether response times were log-transformed). However, the item-level priming effects did not correlate over tasks. Prime–target pairs such as *labor–work*, for which a large priming effect was found using the speeded word fragment completion task, did not show priming in the lexical decision task and vice versa for, for instance, *radish–bitter*. This inconsistency was attributed to diverging baseline response times. That is to say, participants were slow to complete fragments such as w_rk (correct completion is *work*) whereas they easily recognized *work* as being an existing word. The reverse reasoning holds for bitt_r (correct completion is *bitter*). As priming effects are linked with baseline response times and baseline response times correlate meagerly over tasks, it is conceivable that item-level priming effects are uncorrelated across tasks (especially when factoring in that priming effects are not very stable *within* tasks). The observation that the magnitude of item-level priming effects varies with baseline response time is consistent with the idea that reliance on the prime is greater for difficult items (Balota et al., 2008; Scaltritti, Balota, & Peressotti, 2013). The prime reliance account, as presented by Scaltritti et al., postulates that a semantically related prime speeds up processing more for difficult targets (e.g., low-frequency words, visually degraded words) than for easy targets (e.g., short, high-frequency words). However, it is debated whether prospective and/or retrospective priming underlie this phenomenon. Balota et al. (2008) posited that both play a role in recognizing visually degraded words (see also Yap, Balota, & Tan, 2013). They observed a shift in the response time distribution in the degraded condition, meaning that the priming effect was always larger compared with the clear target condition. The priming effect was boosted even for easily recognized items, which was attributed to a forward priming mechanism. However, this effect was stronger for items that were particularly hard to decipher, presumably because participants also used a controlled prime retrieval process. Recently, Thomas et al. (2012) argued that *only* the latter mechanism drives the degradation effect on priming. They examined symmetrical associations (SYM) as well as asymmetrical forward and backward associations (FA and BA, respectively) and found a comparable boost in priming due to target degradation for

[8] There were 304 trials in Experiment 1 and 288 in Experiment 2, resulting in, respectively, 303 and 287 pairs because of its continuous nature. Thus, the relatedness proportion is only .125 (i.e., 38/303 and 36/287). Note that this number may be a little higher for some participants because of the random ordering of pairs (e.g., *shower–chocolate* followed by *cake–vault*).

Table 2 Summary of the similarities and differences between the speeded word fragment completion task and the lexical decision task (Experiment 2 vs. Experiment 3)

Similarities	Differences with the lexical decision task
Reliability priming effect	Higher reliability RTs
Magnitude priming effect	Longer RTs
Contextual diversity predicts RT	Lower error rate
	Item-level priming effects
	Orthographic neighborhood size of distractor predicts RT

SYM and BA pairs, but no boost in priming for FA pairs.[9] According to Thomas and colleagues, the boost in priming for degraded targets is due to semantic matching, which depends on the presence of a backward association (but see Robidoux, Stolz, & Besner, 2010, for conflicting evidence). As to whether prospective and/or retrospective priming contributed to the effects observed in the speeded word fragment completion task is not unambiguously clear even though the employed methodology typically reduces (or eliminates) retrospective priming. Because our primary goal was merely to establish if semantic priming can be captured, we did not select BA pairs. Also, the FA and SYM pairs in our experiments were not matched on crucial variables such as word frequency and baseline response time, so any potential difference would be hard to interpret.

Finally, response times in both tasks could be predicted by contextual diversity (i.e., the number of contexts in which a word occurs), but not by word length. Intriguingly, response times in the speeded word fragment completion task were also related to the orthographic neighborhood size of the distractor. The term distractor is in this context defined as an incorrect completion of the fragment (e.g., for bitt_r, the distractor is *bittar*, because the correct completion would be *bitter*). The more orthographic neighbors the distractor has, the longer it takes participants to correctly fill in the gap. This finding entails an interesting quality of the speeded word fragment completion task. Because our results and previous work show that the magnitude of priming varies with baseline response time, it would be convenient if we were able to increase the latter. This is rather difficult to accomplish in a lexical decision task because there is not much to manipulate except the nature of the pseudowords and the way of presenting the stimuli (e.g., visually degraded). The speeded word fragment completion task is a bit more flexible in that respect, because one can choose to omit a particular letter or select certain distractors, which in turn influence the baseline response times. It also explains why the magnitude of the priming effect in general was not significantly larger in the speeded word fragment completion task. Because some of the word fragments were fairly easy to complete, target processing does not benefit as much from the semantically related prime. Put differently, target processing is only hindered when specific letters are omitted and/or when distractors have many orthographic neighbors. Some targets, such as bitt_r, are not sufficiently degraded to prompt recognition difficulties; hence, no stronger priming effect is observed.

Now that we have identified some tools to increase target difficulty, it enables us to examine semantic priming more rigorously. Concretely, priming effects for short, high-frequency target words may be hard to reveal using a traditional lexical decision task, as illustrated in Experiment 3. Increasing target difficulty by selectively deleting letters and choosing distractors with many orthographic neighbors can increase reliance on prime information, resulting in stronger priming effects. Consequently, it allows for a detailed study of the most central items within a word association network, which often yield no priming effects in a lexical decision paradigm because they are immediately recognized. This claim was tested in Experiment 4. Here, we selected only short, high-frequency words and presented participants both with the speeded word fragment completion task and the lexical decision task. The results revealed a strong priming effect of 73 ms or 87 ms, depending on whether the data were log-transformed, in the former task, but no significant effect in the latter.

In conclusion, the main goal of this article was to find a task that allowed for a more fine-grained investigation of semantic activation. This was motivated by the observation that in the often-used lexical decision task, shallow processing of letter strings may be sufficient to discriminate most words from nonwords (Rogers et al., 2004). The speeded word fragment completion task, as introduced here, sought to provide an alternative that involved more elaborate processing. The rationale was that the speeded word fragment completion task in a way resembled the visual degradation paradigm (Balota et al., 2008; Stolz & Neely, 1995). Visual degradation is usually accomplished by alternately presenting stimulus and mask or by manipulating the contrast, but deleting a letter from a word can also be considered as a special form of degradation. As in "conventional" degradation, target recognition is hindered; hence, additional processing is required. Nevertheless, the present experiments are somewhat agnostic as to whether the speeded word fragment completion task indeed involves deeper processing, although it should be pointed out that response times in the fragment completion task are about 200–300 ms longer compared with the lexical decision task. But regardless of the underlying process, the speeded word fragment completion task did serve its purpose. That is, it is able to obtain (strong) priming effects, when the lexical decision task may fail to do so (see Experiment 4). It thus enables us to further examine the role of variables such as associative strength in semantic

[9] Note that the BA targets in the Thomas et al. study (2012) were significantly less frequent than the FA targets, with the SYM targets falling somewhere in between. Given that Scaltritti et al. (2013) found a significant Priming × Frequency × Stimulus quality (i.e., target degraded or not) interaction, it is unclear whether the pattern of results in Thomas et al. is (partly) a frequency effect in disguise. Indeed, Scaltritti and colleagues found a stronger Priming × Stimulus quality interaction for less-frequent target words.

activation, covering also the most important concepts of our mental lexicon. Indeed, Experiment 4 consisted of only short, highly frequent words, and the speeded word fragment completion task has been shown to be especially sensitive to priming effects in those instances. The lexical decision task might still occasionally find priming for short, highly frequent words, but those effects may be harder to detect because such words are readily recognized, which in turn reduces the influence of the prime. It becomes even more of an issue if one wants to discriminate between strongly associated and weakly associated prime–target pairs or examine indirectly related pairs. It is conceivable that the potential priming effects are even smaller in the latter cases and may thus go undetected. The speeded word fragment completion task could offer an alternative that might be more sensitive to such subtle effects.

As argued in the introduction, the speeded word fragment completion task has some other potentially interesting attributes. First of all, there is no need for experimenters to construct pseudowords. Because pseudoword trials are considered to be fillers and hence are dropped from most analyses, one needs more trials in a lexical decision task for the same amount of data. Thus, the speeded word fragment completion task is a more efficient alternative.

Secondly, the speeded word fragment completion task is similar to a naming study, in that the required response to the target is unconfounded with the prime–target association. Specifically, one cannot derive the answer to the target from its relation with the prime. In a lexical decision task, on the other hand, participants may develop the strategy of retrospectively checking whether the prime and target are related, because the task provides information regarding the lexical status of the target. That is, if the prime and target are semantically related (e.g., *tomato–lettuce*) then the target is *always* a word, whereas if they are unrelated, the target can be a word (e.g., *guitar–lettuce*) *or* a nonword (e.g., *guitar–prettuce*). Participants may adopt a semantic matching strategy, which in turn leads to faster response times in the related condition than in the unrelated condition. Unfortunately, such a strategic priming effect is inseparable from automatic priming effects. It has been argued that the naming paradigm eliminates the retrospective semantic matching strategy that typically arises in a lexical decision task (Neely & Keefe, 1989). A similar argument can be made for the speeded word fragment completion task,[10] although the present data are uninformative as to whether semantic matching is indeed ruled out.

Finally, the speeded word fragment completion task is more engaging. In Experiment 4, in which participants completed both a lexical decision and a speeded word fragment completion block, the latter task was perceived as less annoying and easier. As a matter of fact, all participants' ratings for the speeded word fragment completion task ranged from *not annoying at all* to *neutral*. Furthermore, when asked to indicate which task they would prefer doing for 1 hr (as opposed to the 5 to 10 min it took in the actual experiment), all but 3 participants out of 29 chose the speeded word fragment completion task. Taken together, this indicates that the speeded word fragment completion task is rather engaging, in that it may resemble a word puzzle. The former has been argued to foster the intrinsic motivation of participants, which also encourages them to be more focused (Deci & Ryan, 1985).

As noted in the introduction, the most frequently used paradigm to study semantic priming is the lexical decision task. Hence, throughout the article, it was used as the gold standard against which we compared the speeded word fragment completion task. However, other paradigms, such as naming (i.e., pronouncing words out loud) or semantic categorization (i.e., deciding whether a concept belongs, for instance, to the category *animals* or *artefacts*), have been used to examine semantic priming as well. An interesting question now is how the paradigm introduced here compares with these tasks. In what follows, we will discuss (potential) similarities and differences, starting with the naming task, because this is the most popular paradigm in priming research aside from the lexical decision task.

The naming task shares several attractive properties with the speeded word fragment completion task in that they both require no pseudowords and that the response to the target is independent from the prime–target relationship. In addition, in the naming task, and also in the lexical decision task, *all* words can be used as targets. The speeded word fragment completion task in its present form, on the other hand, uses only stimuli that contain an *a* or an *e* (at least in Experiments 2 and 4; in Experiment 1, any vowel can be omitted) and that have a unique correct solution.[11] A disadvantage of the naming task is its more complex setup, involving a voice input device and the difficulties associated with it. For instance, Kessler, Treiman, and Mullennix (2002) reported that voice response time measurements depend on the initial phoneme of a word. Furthermore, naming latencies and fixation durations are generally the shortest for highly frequent, relatively short words (see, e.g., Kliegl, Grabner, Rolfs, & Engbert, 2004; Yap & Balota, 2009). So, as was the case in the lexical decision task, such stimuli may be easily recognized, thus minimizing the potential influence of the prime. In contrast, the speeded word

[10] Note that the *continuous* lexical decision task has been argued to prevent semantic matching as well (McNamara & Altarriba, 1988). Nevertheless, the presence of a semantic relation in this task still predicts *word* 100 % of the time. Hence, the speeded word fragment completion task is more stringent.

[11] Throughout the three experiments with the speeded word fragment completion task, we always used vowels as the omitted letter (i.e., *a*, *e*, *i*, *o*, and *u* in Experiment 1; *a* and *e* in Experiments 2 and 4). The rationale was to use letters that are frequently used in everyday language while at the same time keeping the instructions straightforward and easy to remember. The latter is probably only an issue in the variant with five response options. That is, if we had picked five highly frequent consonants, it would arguably be more demanding to remember the response options. However, there is no a priori reason why the obtained results would not generalize to a paradigm that uses consonants; but that is something to examine in future research.

fragment completion task has been shown to yield large priming effects in these instances. This might render the speeded word fragment completion task better suited to examine priming in that respect, but future research is needed to clearly establish this potential benefit.

Studies that use semantic categorization as a paradigm to examine priming are less numerous and are often not considered in meta-analyses (Hutchison, 2003; Lucas, 2000). Lucas, for example, argued that the emphasis on semantics promotes the use of strategies to tackle the task. One concerning issue is that relatedness is frequently confounded with response congruency. That is, if the task is to categorize concepts as being animate or inanimate, related primes and targets are mostly *both* animate or inanimate (e.g., *tomato–lettuce*), whereas unrelated pairs are incongruent (e.g., *horse–lettuce*; de Groot, 1990). Hence, one can predict the correct response to the target in advance, based on the prime. It is possible, though, to construct the task such that targets have to be categorized on a basis that is orthogonal to the dimension on which prime and target are related (e.g., categorizing based on the typical color of the underlying concept). This does constrain the prime–target pairs that can be used within this framework, because there has to be some consistency among the stimuli; in this example, in terms of color of the concepts. Especially when it comes to abstract concepts, such as *work*, *money*, and *warm*, it might prove difficult to design a task that involves these stimuli. The semantic categorization task is also similar to the speeded word fragment completion task in some respects. Relative to the lexical decision task, they both do not require pseudowords and they are (presumably) more difficult; hence, the prime has a greater potential to exert its influence. Further research comparing both paradigms and, more specifically, the consistency (or lack thereof) in terms of item-level priming effects, could shed more light on the latter issue and potentially yield interesting conclusions regarding the underlying structure of the mental lexicon.

Conclusion

The present research introduces a different paradigm to examine semantic priming. The speeded word fragment completion task has some attractive qualities, in that it is an efficient and engaging task. Furthermore, it has been shown to capture semantic priming for highly frequent words that are central in people's associative network, whereas the lexical decision task failed to obtain a priming effect for those items. In summary, the speeded word fragment completion task may prove a viable alternative to lexical decision for examining semantic priming.

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Appendixes

Appendix A

Table 3 Prime–target pairs from Experiment 1. The first and second columns give the English translations; the third and fourth columns show the Dutch word fragments, with the correct completions in parentheses

Primes	Targets	Prime fragments	Target fragments
scissors	paper	sch_ar (schaar)	pap_er (papier)
wheat	flour	t_rwe (tarwe)	me_l (meel)
soul	body	zi_l (ziel)	l_chaam (lichaam)
living room	salon	liv_ng (living)	sal_n (salon)
wild boar	pig	_verzwijn (everzwijn)	vark_n (varken)
yolk	egg white	d_oier (dooier)	eiw_t (eiwit)
clay	loam	kle_ (klei)	le_m (leem)
raspberry	strawberry	fr_mboos (framboos)	aardbe_ (aardbei)
lieutenant	colonel	l_itenant (luitenant)	k_lonel (kolonel)
embryo	fetus	embry_ (embryo)	foet_s (foetus)
toddler	baby	pe_ter (peuter)	b_by (baby)
planet	stars	pl_neet (planeet)	sterr_n (sterren)
zebra	horse	zebr_ (zebra)	pa_rd (paard)
lizard	salamander	haged_s (hagedis)	s_lamander (salamander)
neuron	atom	ne_ron (neuron)	_toom (atoom)
chisel	hammer	be_tel (beitel)	ham_r (hamer)
rectangle	square	rechth_ek (rechthoek)	v_erkant (vierkant)
apartment	house	app_rtement (appartement)	h_is (huis)
czar	emperor	tsa_r (tsaar)	ke_zer (keizer)
pin	needle	sp_ld (speld)	na_ld (naald)
celery	leek	s_lder (selder)	pr_i (prei)
walrus	seal	w_lrus (walrus)	zeeh_nd (zeehond)
lettuce	tomato	sl_ (sla)	t_maat (tomaat)
slippers	house shoe	sl_ppers (slippers)	p_ntoffels (pantoffels)
autumn	winter	h_rfst (herfst)	w_nter (winter)
satin	silk	s_tijn (satijn)	zijd_ (zijde)
dryer	washing machine	dro_gkast (droogkast)	w_smachine (wasmachine)
judge	lawyer	recht_r (rechter)	adv_caat (advocaat)
captain	sailor	kap_tein (kapitein)	m_troos (matroos)
cowboy	Indian	c_wboy (cowboy)	_ndiaan (indiaan)
hare	rabbit	h_as (haas)	k_nijn (konijn)
organ	piano	org_l (orgel)	pian_ (piano)
shampoo	soap	shamp_o (shampoo)	ze_p (zeep)
dragon	knight	dra_k (draak)	ridd_r (ridder)
beech	oak	b_uk (beuk)	_ik (eik)
uncle	nephew	o_m (oom)	n_ef (neef)
stomach	intestine	ma_g (maag)	d_rm (darm)

Table 3 (continued)

Primes	Targets	Prime fragments	Target fragments
prince	king	pr_ns (prins)	k_ning (koning)
horse-fly	fly	da_s (daas)	vl_eg (vlieg)
letters	digits	l_tters (letters)	cijf_rs (cijfers)
bracelet	chain	_rmband (armband)	kett_ng (ketting)
date	fig	d_del (dadel)	v_jg (vijg)
sprinkler	watering can	spr_eier (sproeier)	gi_ter (gieter)
sergeant	major	serge_nt (sergeant)	majo_r (majoor)
hearts	clubs	hart_n (harten)	kl_veren (klaveren)
tornado	hurricane	t_rnado (tornado)	orka_n (orkaan)
red	blue	r_od (rood)	bla_w (blauw)
metro	train	m_tro (metro)	tre_n (trein)
croquette	purée	kr_ket (kroket)	p_ree (puree)
master	teacher	m_ester (meester)	j_f (juf)
peas	carrots	_rwten (erwten)	wort_len (wortelen)
helicopter	aircraft	helik_pter (helikopter)	vl_egtuig (vliegtuig)
scampi	shrimp	scamp_ (scampi)	g_rnaal (garnaal)
abbey	monastery	_bdij (abdij)	klo_ster (klooster)
lion	tiger	lee_w (leeuw)	t_jger (tijger)
pistol	rifle	p_stool (pistool)	g_weer (geweer)
cough	sneeze	h_esten (hoesten)	n_ezen (niezen)
lute	guitar	lu_t (luit)	g_taar (gitaar)
wizard	witch	t_venaar (tovenaar)	h_ks (heks)
fork	spoon	v_rk (vork)	lep_l (lepel)
nurse	doctor	v_rpleegster (verpleegster)	d_kter (dokter)
measuring rod	ruler	l_niaal (liniaal)	meetl_t (meetlat)
lay brother	priest	l_ek (leek)	pri_ster (priester)
thunder	lightning	dond_r (donder)	bl_ksem (bliksem)
count	baron	gra_f (graaf)	b_ron (baron)
village	city	d_rp (dorp)	st_d (stad)
diesel	gasoline	d_esel (diesel)	b_nzine (benzine)
straw	hay	str_ (stro)	hoo_ (hooi)
carnation	rose	anj_r (anjer)	r_os (roos)
palace	castle	p_leis (paleis)	k_steel (kasteel)
platinum	silver	pl_tina (platina)	zilv_r (zilver)
sabre	épée	s_bel (sabel)	deg_n (degen)
myth	legend	myth_ (mythe)	l_gende (legende)
pepper	salt	pep_r (peper)	z_ut (zout)
truck	car	vr_chtwagen (vrachtwagen)	a_to (auto)
hail	snow	hag_l (hagel)	snee_w (sneeuw)

Appendix B

Table 4 Prime–target pairs from Experiments 2 and 3. The first and second columns give the English translations; the third and fourth columns show the Dutch word fragments, with the correct completions in parentheses

Primes	Targets	Prime fragments	Target fragments
fennel	anise	v_nkel (venkel)	_nijs (anijs)
donkey	bray	_zel (ezel)	b_lken (balken)
valley	mountains	v_llei (vallei)	berg_n (bergen)
spoon	cutlery	lep_l (lepel)	b_stek (bestek)
witch	broom	h_ks (heks)	b_zem (bezem)
absurd	bizarre	_bsurd (absurd)	biz_r (bizar)
panic	fire	p_niek (paniek)	br_nd (brand)
éclair	pastry	_clair (eclair)	geb_k (gebak)
sound	noise	kl_nk (klank)	g_luid (geluid)
number	figure	numm_r (nummer)	g_tal (getal)
alarm	danger	al_rm (alarm)	g_vaar (gevaar)
moose	antlers	el_nd (eland)	g_wei (gewei)
glazed frost	slippery	ijz_l (ijzel)	gl_d (glad)
intense	fierce	int_ns (intens)	h_vig (hevig)
sober	scanty	sob_r (sober)	k_rig (karig)
organ	church	org_l (orgel)	k_rk (kerk)
wart	ugly	wr_t (wrat)	l_lijk (lelijk)
tenor	opera	t_nor (tenor)	oper_ (opera)
gift	parcel	c_deau (cadeau)	p_kje (pakje)
pineapple	juicy	an_nas (ananas)	s_ppig (sappig)
pocket knife	sharp	zakm_s (zakmes)	sch_rp (scherp)
slender	narrow	teng_r (tenger)	sm_l (smal)
taxi	city	t_xi (taxi)	st_d (stad)
summer	beach	zom_r (zomer)	str_nd (strand)
uncle	aunt	nonk_l (nonkel)	t_nte (tante)
balcony	terrace	b_lkon (balkon)	terr_s (terras)
puma	tiger	poem_ (poema)	tijg_r (tijger)
stallion	foal	h_ngst (hengst)	veul_n (veulen)
dragonfly	pond	lib_l (libel)	vijv_r (vijver)
baton	weapon	m_trak (matrak)	w_pen (wapen)
sauna	warm	saun_ (sauna)	w_rm (warm)
pea	carrot	_rwt (erwt)	wort_l (wortel)
okapi	zebra	ok_pi (okapi)	zebr_ (zebra)
sofa	couch	sof_ (sofa)	z_tel (zetel)
leprosy	disease	lepr_ (lepra)	ziekt_ (ziekte)
satin	silk	s_tijn (satijn)	zijd_ (zijde)
merely	solely	lout_r (louter)	_lleen (alleen)
radish	bitter	r_dijs (radijs)	bitt_r (bitter)
figs	dates	vijg_n (vijgen)	d_dels (dadels)
sabre	épée	s_bel (sabel)	deg_n (degen)
chemistry	physics	ch_mie (chemie)	fysic_ (fysica)
balance	money	s_ldo (saldo)	g_ld (geld)
apple	healthy	_ppel (appel)	g_zond (gezond)

Table 4 (continued)

Primes	Targets	Prime fragments	Target fragments
marble	hard	m_rmer (marmer)	h_rd (hard)
knight	armor	ridd_r (ridder)	h_rnas (harnas)
beetle	insect	k_ver (kever)	ins_ct (insect)
partridge	hunting	p_trijs (patrijs)	j_cht (jacht)
mixer	kitchen	mix_r (mixer)	keuk_n (keuken)
freight	load	vr_cht (vracht)	l_ding (lading)
supple	lithe	soep_l (soepel)	l_nig (lenig)
slogan	motto	slog_n (slogan)	leuz_ (leuze)
authority	power	g_zag (gezag)	m_cht (macht)
cape	coat	c_pe (cape)	mant_l (mantel)
cement	mortar	c_ment (cement)	mort_l (mortel)
oyster	mussel	oest_r (oester)	moss_l (mossel)
pajamas	night	pyj_ma (pyjama)	n_cht (nacht)
carton	paper	k_rton (karton)	p_pier (papier)
mink	fur	n_rts (nerts)	p_ls (pels)
oven	pizza	ov_n (oven)	pizz_ (pizza)
cactus	plant	c_ctus (cactus)	pl_nt (plant)
neat	clean	netj_s (netjes)	prop_r (proper)
gamba	scampi	g_mba (gamba)	sc_mpi (scampi)
woodpecker	beak	sp_cht (specht)	snav_l (snavel)
penalty	punishment	boet_ (boete)	str_f (straf)
napkin	table	s_rvet (servet)	t_fel (tafel)
pheasant	bird	faz_nt (fazant)	vog_l (vogel)
onion	cry	_juin (ajuin)	wen_n (wenen)
labor	work	_rbeid (arbeid)	w_rk (werk)
hail	winter	hag_l (hagel)	wint_r (winter)
mattress	soft	m_tras (matras)	z_cht (zacht)
limp	weak	sl_p (slap)	zw_k (zwak)
magpie	black	_kster (ekster)	zw_rt (zwart)

Appendix C

Table 5 Prime–target pairs from Experiment 4. The first and second columns give the English translations; the third and fourth columns show the Dutch word fragments, with the correct completions in parentheses

Primes	Targets	Prime fragments	Target fragments
homeless	poor	d_kloos (dakloos)	_rm (arm)
dairy product	milk	zuiv_l (zuivel)	m_lk (melk)
camping	tent	k_mperen (kamperen)	t_nt (tent)
checkers	game	d_mmen (dammen)	sp_l (spel)
hill	mountain	heuv_l (heuvel)	b_rg (berg)
pilot light	gas	waakvl_m (waakvlam)	g_s (gas)
setback	bad luck	t_genslag (tegenslag)	p_ch (pech)
sauna	warm	saun_ (sauna)	w_rm (warm)
balance	money	s_ldo (saldo)	g_ld (geld)

Table 5 (continued)

Primes	Targets	Prime fragments	Target fragments
route	road	rout_ (route)	w_g (weg)
finger	hand	ving_r (vinger)	h_nd (hand)
loan	bank	l_ning (lening)	b_nk (bank)
dramatic	bad	dr_matisch (dramatisch)	_rg (erg)
arable	field	_kker (akker)	v_ld (veld)
gift	parcel	c_deau (cadeau)	p_kje (pakje)
armor	tank	p_ntser (pantser)	t_nk (tank)
panic	fire	p_niek (paniek)	br_nd (brand)
meadow	grass	weid_ (weide)	gr_s (gras)
labor	work	_rbeid (arbeid)	w_rk (werk)
safe	calm	g_rust (gerust)	k_lm (kalm)
legs	table	pot_n (poten)	t_fel (tafel)
wart	ugly	wr_t (wrat)	l_lijk (lelijk)
paintbrush	paint	p_nseel (penseel)	v_rf (verf)
mink	fur	n_rts (nerts)	p_ls (pels)
penalty	punishment	boet_ (boete)	str_f (straf)
shard	glass	sch_rf (scherf)	gl_s (glas)
dear	darling	liefst_ (liefste)	sch_t (schat)
visitor	guest	b_zoeker (bezoeker)	g_st (gast)
recently	just	onl_ngs (onlangs)	p_s (pas)
piece of furniture	closet	meub_l (meubel)	k_st (kast)
strategy	plan	str_tegie (strategie)	pl_n (plan)
coincidence	luck	toev_l (toeval)	gel_k (geluk)
organ	church	org_l (orgel)	k_rk (kerk)
intense	fierce	int_ns (intens)	h_vig (hevig)
stir	spoon	roer_n (roeren)	l_pel (lepel)
remainder	rest	ov_rschot (overschot)	r_st (rest)
marble	hard	m_rmer (marmer)	h_rd (hard)
baton	weapon	m_trak (matrak)	w_pen (wapen)
start	beginning	st_rt (start)	b_gin (begin)
level	straight	w_terpas (waterpas)	r_cht (recht)

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