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Early semantic activation in a semantic categorization task with masked primes: Cascaded or not?

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ABSTRACT

The assumption that activation is cascaded implies that the semantic properties of all neighbors of the input word are activated to varying degrees. This assumption is tested using masked priming in a semantic categorization experiment, where the prime belongs to the same category as the target (a congruent prime), or to a different category (an incongruent prime). In Experiment 1, the prime was a nonword neighbor of an exemplar or non-exemplar of the category, and a clear congruence effect was produced, even though the orthographic overlap was fairly low (e.g., *lucchibi-zucchini*). In Experiment 2, the prime was a word neighbor (e.g., *capable-cabbage*), which eliminates the possibility that the prime was simply interpreted as equivalent to the nearest task-relevant word, but a congruence effect was still obtained. Experiment 3 replicated this effect. Experiments 4–6 investigated the possible role of the category using a two-alternative forced choice discrimination task, where the task was simply to guess which of two subsequently presented words was more similar in meaning to the masked word. Despite better than chance performance when the masked word was related to one of the alternatives, performance was at chance when the masked word was a neighbor of a word that was related to one of the alternatives, indicating that semantic activation is not normally cascaded. It is concluded that the categorization task fundamentally alters the way in which a masked word is processed.

Introduction

A fundamental distinction between different architectural models of visual word recognition is the contrast between staged models (also known as "form-first" models), and cascaded models (McClelland, 1979). In a staged model of lexical processing, it is assumed that the process of identifying a word (i.e., finding and confirming a match between the input and a lexical representation) must be completed before retrieving its semantic properties. This is true in serial models (Forster, 1976; Forster & Hector, 2002), where a search process must identify a lexical entry that is a perfect match for the input before any higher-level processing occurs. It is also true in parallel activation models such as the logogen model (Morton, 1969), where activation in a given logogen must reach threshold before semantic activation can occur. Such a restriction is explicitly rejected in parallel activation models based on the Interactive Activation Model (McClelland & Rumelhart, 1981). In this type of model, there is no threshold mechanism, and activation is continuously passed from one level to the next. A prominent example of such an approach is the Dual Route Cascaded model of word reading (DRC) proposed by Coltheart, Rastle, Perry, Langdon, and Ziegler (2001). In this model, activation is passed forward to a semantic level continuously. Because of the method by

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which activation is generated, all words that have any orthographic overlap with the input must receive some activation, and hence the semantic properties of these words must also be activated to varying degrees. This would result in a very complex pattern of activity at the semantic level, which would remain so until the competitive process between word units was resolved, and only one word unit remained active. The same conclusion applies in the case of connectionist models of word recognition (e.g., Harm & Seidenberg, 2004), where activation is immediately passed from orthographic units to both phonological and semantic units, with feedback from semantic units playing a role in eventually resolving the input.

Coltheart et al. (2001) justify the cascaded assumption on the following grounds. If the system is thresholded, then a nonword could never activate the properties of a word. However, as Glushko (1979) observed, the pronunciation of nonwords is influenced by their similarity to words. For example, Glushko showed that the pronunciation latencies of nonwords such as *heaf* that overlapped with an inconsistent word (*deaf*) were longer than the latencies of nonwords such as *hean* that overlapped with a consistent word (e.g., *bean*). The implication is that the phonology of *deaf* must have been activated by the nonword *heaf*, which would violate the assumptions of a thresholded model. Thus the phonological properties of all words that overlap orthographically with the input must be presumed to be activated. Thus cascaded activation allows for interaction between processing modules, in this case, both at the level of form. Whether the same applies to modules operating at different levels is another matter. Despite the importance of this issue for an understanding of the basic architectural features of information processing, relatively little effort has been devoted to demonstrating the existence of cascaded semantic activation.

One piece of evidence that is certainly consistent with cascaded activation is the so-called *turple* effect. Forster and Hector (2002) found that in a semantic categorization task, nonword neighbors of words were categorized more slowly than a nonword with no neighbors if the word neighbor was an exemplar of the category. This was not the case for nonword neighbors of non-exemplars. Thus, when the task was to detect animal names, a nonword such as *turple* (neighbor of *turtle*) was rejected more slowly than a nonword such as *firtan* (neighbor of no word), but a nonword such as *tabric* (neighbor of *fabric*) did not take any longer to reject than *firtan*, as it would have in a lexical decision task. This result supports cascaded activation in that it implies that semantic processing occurs early enough to interact with form processing. The specific nature of this interaction could include forcing a more careful examination of the spelling of the candidate, or extending the deadline for a "no" decision. Rodd (2004) extended this finding by performing a similar experiment but with word neighbors of animal exemplars (e.g. *leotard* for *leopard*) and of non-exemplars (e.g. *cellar* for *collar*). Animal neighbors were found to significantly increase reaction time when participants were monitoring the input for animal names, but not when they were monitoring for plant names. Rodd concluded that associative relations (e.g. *puppy* and *kitten*) were not the cause of the effect due to low association between adjacent items, but rather that the category at hand (*animal* vs. *plant*) was providing the semantic context for the difference. A participant looking for animals would inspect each word to be categorized in terms of members of the animal category, and a participant monitoring for plants would do so in terms of members of the plant category. However, Rodd concluded that the data do not distinguish between a staged or a cascaded account.

Bowers, Davis, and Hanley (2005) used a semantic categorization task in which some of the non-exemplar targets were orthographically related to an exemplar of the category, e.g., is *hatch* an item of clothing? Slower responses were obtained if the target letters contained an exemplar as a subset (*hatch-hat*) or if the target letters were a subset of an exemplar (*bee-beer*). Hino, Lupker, and Taylor (2012) obtained similar effects with a semantic relatedness task, showing that if the second member of a pair of unrelated words was orthographically similar to a word that was related to the first member (e.g., MISSILE-POCKET), responses were slower. No such effect was obtained when the target word was phonologically similar to the first word.

Pecher, Zeelenberg, and Wagenmakers (2005) examined long-lag repetition priming with a semantic categorization task (*animate* vs. *inanimate*), and showed that a word like *cat* would be responded to faster if the participant had previously seen *rat* than if she had seen *mat*. They further tested words with different neighborhood characteristics in terms of animacy, comparing reaction time and error rate in deciding the animacy of words with congruent neighbors like *fridge* (cf. *bridge* and *fringe*) with those of words like *cheek* (cf. *check* and *creek*), where congruence simply means belonging to the same semantic category. The category used in this experiment (animacy) was a much broader category than those used in previous studies. Their explanation of the data involves feature monitoring, in which semantic categorization is accomplished by means of selective monitoring of feature activation at the semantic level, with negative features such as "inanimate" activated by logically incompatible features such as "made of stone".

All of the studies reviewed above used experimental items that were consciously perceived and responded to. This leaves open the question of how early in lexical access the evidence for semantic categorization is gathered. In order to determine whether briefly and unconsciously perceived stimuli could influence semantic categorization, indicating early activation, the experiments described in this paper used masked primes (Forster & Davis, 1984). Masked primes, which are stimuli that are hidden from conscious perception by being presented briefly following a forward mask, are nevertheless capable of influencing the speed and accuracy of a person's response to stimuli that immediately follow them. By varying which target a given prime appears with, one can directly compare the differential effect of that prime on the response. Using this approach allows a more direct examination of the early stages of semantic categorization when the stimulus has not reached conscious identification.

In the initial series of experiments to be reported, we test for the existence of a congruence effect. This occurs when the status of the masked prime with respect to the category differs from that of the target (e.g., Bowers et al., 2005; Dehaene et al., 1998; Finkbeiner & Caramazza, 2008). For example, if the category is *ANIMAL*, the response to a nonexemplar such as *WALNUT* would be slower if it was preceded by an exemplar prime (e.g. *tiger*) rather than a nonexemplar prime (e.g., *carpet*), even though subjects are unaware of the prime (e.g., Finkbeiner & Caramazza, 2008; Forster, Mohan, & Hector, 2003; Quinn & Kinoshita, 2008). The situation in the present series of experiments is slightly different. Instead of presenting an exemplar as a prime, we present a *neighbor* of an exemplar (e.g., *togar*). The implication of a congruence effect in this case is that the prime must have activated the semantic properties of its exemplar neighbor, which is what a cascaded view of lexical processing would predict. In three experiments, a clear congruence effect is obtained with both nonword and word primes. We then consider the possible role that the categorization task itself might play. When a masked prime is presented without any requirement to categorize a subsequent target, there is no evidence that the semantic properties of neighbors are activated.

An additional feature of the present series of experiments is that the neighbor of an exemplar was not created by a single letter substitution (e.g. *turple* from *turtle*), as in previous research. There are several undesirable features of using this procedure. First, the similarity to a word is dependent on length. For example, compare *elephont* and *goam* as neighbors of animal names. Second, when the subject is monitoring for an animal name, an item such as *elephont* might initially be misread as *elephant*, given the high degree of overlap. Such a repair process would mean that the input was registered as an adequate match for the input, in which case, semantic activation would be expected, which is not the same as cascaded activation produced by a neighbor. A third problem is that it is difficult to find word neighbors for many exemplars (e.g., what is a word neighbor of *lettuce*?). For these reasons, in the experiments described here, neighbors were selected using the metric provided by the Spatial Coding Model (Davis, 2010), which produces a measure of orthographic similarity that takes into account such factors as variable length and relative letter position. This measure, which we refer to as a Spatial Coding Model (SCM) match coefficient, ranges from 0, indicating no letters in common, to 1, indicating identical letter strings. The substitution neighbors *elephont-elephant* and *goam-goat*, for example, have very different SCM similarities, 0.90 and 0.67, respectively. To make the items more comparable, *alechant* would be a better neighbor for *elephant* (SCM match = 0.70). Furthermore, the SCM metric takes into account factors such as transposition, letter deletion, and letter insertion, factors which are known to affect masked form priming. As a non-binary scale, the SCM match coefficient not only takes into account a greater number of kinds of similarity but can also produce a more sensitive range of perceived similarity than the two-valued scale that has been used in the past.

Finally, for each category, the nonexemplar targets all belonged to a single category, which tends to strengthen the congruence effect. This makes the categorization task more like an *either-or* task. So if the positive category was *animal*, the nonexemplars might all be colors, instead of using a heterogenous set of words as nonexemplar targets.

Experiment 1

In this experiment, nonword neighbors are used to test for a congruence effect. In case no congruence effect was observed, a standard form priming condition was included, in which the prime was a neighbor of the target itself.

Method

Participants

A total of 24 undergraduate students enrolled in an introductory psychology course at the University of Arizona participated in the experiment, for which they received course credit.

Materials and design

Four positive exemplar categories were used: *profession*, *city*, *country*, and *vegetable*—each of which was matched to a contrasting category—*animal*, *boy's name*, *girl's name*, and *tool*, respectively. Fifteen exemplars of high typicality were chosen (plus two practice items) from each category to be targets. A nonword prime was constructed from each target word by substituting for a variable number of letters, deleting or transposing letters, such that the prime was a neighbor with an SCM similarity value between 0.60 and 0.75 (average 0.68). The reason for choosing this range of similarity was to reduce the probability of (mistaken) identity priming while still maintaining form priming: if the items were too similar, then they might be taken as identical, whereas if they were too dissimilar, there could be no priming at all. Thus a single letter substituted nonword prime such as *radith* would not be used as a neighbor of *RADISH*, because its SCM similarity index would exceed 0.75 (SCM similarity = 0.88). Instead, a double substitution nonword prime such as *camish* was used (SCM similarity = 0.63). However, for shorter words, a one letter substitution neighbor was usually sufficient (e.g., *raka* for *rake*, SCM similarity = 0.67).

Three nonword primes were selected for each target word. For example, if the prompted category was CITY NAME (and all nonexemplars were boy's names), then one prime was a nonword neighbor of the target word itself, in lower case letters, making a pair like *bailmer–BOULDER*. These items are referred to as the Form prime condition. The second was a congruent prime, i.e. a neighbor of a word in the prompted category, making a pair such as *biami–BOULDER*. The last was an incongruent prime, i.e. a neighbor of a word that was in the contrasting category, such as *joer–BOULDER* (*joer* being a neighbor of *Joel*). Neither word length nor frequency were matched between primes and targets.

Half of the targets in each block of stimuli were positive exemplars, i.e. members of the prompted category, and half were negative exemplars, i.e. members of an unprompted category. The purpose of using negative exemplars from a common category was to generate a congruence as well as an incongruence effect if one were there to be found. If no congruence effect were found, the condition in which the prime was an orthographic neighbor to its target would be crucial to show that the lack of a congruence effect was not just the result of insufficient influence of the prime. Three sets of materials were produced, each combining the targets (which never changed except for order within a block) with different primes according to the three conditions: form prime, congruent prime, and incongruent prime. None of the targets were used as primes. Three lists of items were prepared such that each target word was tested with each type of prime, but only appeared once in each list. All items are listed in Appendix A along with the SCM match coefficients.

Procedure

The experiment was controlled by a Pentium PC, using the Windows DMDX software developed by J.C. Forster at the University of Arizona (Forster & Forster, 2003). The experimental items were displayed in black text in a monospaced serif typeface on a white background with a refresh cycle of 10 ms. Each item consisted of a forward mask of hash marks the length of the longest word in the experiment ('############'), a prime displayed for 50 ms in lowercase letters, and a target in uppercase letters displayed until the subject responded. The masking of the prime ensured that no subject could read the primes, and only one reported any awareness of the primes.

The subjects were instructed to decide whether the target was a member of the category identified at the start of each block. Each block began with a statement of the category to be evaluated, followed by four practice items (which were not identified as practice items). The subject was then shown a series of targets, half of which were positive exemplars and half negative exemplars. Each prime condition (congruent, incongruent, neighbor) preceded one third of the positive exemplars and one third of the negative exemplars. The order of the presentation of items within a block was randomized. The order of blocks was not randomized.

The participants were instructed to respond to the target as quickly as possible without making errors by pressing a button marked "YES" if the target was a member of the named category or a button marked "NO" if the target were not a member of the category. After each response, the participants briefly received feedback regarding the correctness of their response and their response time measured in milliseconds. Within a block, items were presented after each response without further input, and participants advanced to the next instruction and block by means of a foot pedal.

Results

Prior to any data analysis, the data from one subject who made more than 20% errors on the word targets were excluded. RTs on trials where an error occurred were discarded (7.9% of the data), as were any RTs that were less than 300 ms or greater than 1500 ms (0.78% of the data). The results were analyzed using linear mixed-effects modeling in R (Baayen, 2008; Baayen, Davidson, & Bates, 2008). This method allows for two crossed random effects (subjects and items), and analyzes the raw RTs for each trial, without aggregating over items or subjects. The procedure followed in each analysis was to first fit a model that included random intercepts for subjects and items. Following the recommendations of Barr, Levy, Scheepers, and Tily (2013), a model using by-subject and by-item random slopes for the effects of interest was fitted, thereby guarding against any anticonservative bias. However, the result of the random slopes analysis is reported only if justified by model comparison and it alters our conclusions (i.e., a significant effect is no longer significant when random slopes are included). Following standard practice, any t value greater than 2.0 was deemed to be significant.

When reporting mean RTs, we simply calculate the mean of the reciprocal RTs, and then report the reciprocal of that value. Results are summarized in Table 1.

A linear mixed effect model was fitted to RT, with target type (exemplar vs. nonexemplar) and prime type (congruent, incongruent, neighbor) as factors. Nonexemplars took longer to classify than exemplars, $t = 5.91$. The contrast between the congruent and incongruent conditions was significant, $t = 3.79$, with slower responses to incongruent items (10 ms for exemplars, 30 ms for nonexemplars). This effect remained significant when random slopes for subjects and items were included. The contrast with the neighbor condition was also significant, $t = 3.94$. No significant interaction was found between prime type and target type ($t < 1$).

Table 1
Average reaction time (RT) in milliseconds and percent error rate for the semantic categorization task, according to type of target (positive exemplar, negative exemplar) and prime (congruent, incongruent, neighbor). Form priming effects are given with congruent primes as a baseline (Experiment 1).

Prime	Exemplars (vegetables)			Nonexemplars (tools)		
	Example	RT	%E	Example	RT	%E
Congruent	*lucchibi-RADISH*	522	7.2	*raka-SHOVEL*	552	7.0
Incongruent	*trawem-RADISH*	532	9.6	*troctoli-SHOVEL*	582	10.7
Form	*carnish-RADISH*	509	9.1	*thovel-SHOVEL*	534	4.1
Congruence		10	2.4		30	3.7
Form priming		13	−1.9		18	2.9

Note: In this example, the positive category was VEGETABLE, negative category TOOL. lucchibi = zucchini, trawem = trowel, carnish = radish, raka = rake, troctoli = broccoli, thovel = shovel.

Discussion

Despite the low degree of orthographic overlap, the nonword primes are capable of generating a reliable congruence effect. In the case of the examples used in Table 1, the positive category was *VEGETABLE*, and the negative category was *TOOL*. The exemplar *RADISH* was classified 10 ms faster when primed with the congruent prime *lucchibi* (from *zucchini*) rather than the incongruent prime *trawem* (from *trowel*). The corresponding effect for nonexemplars was stronger (30 ms), but not significantly so (a similar finding was reported in Forster et al., 2003). In this case, the incongruent prime *troctali* (from *broccoli*) interfered with the response to *SHOVEL* compared to the effect of the congruent prime *raka* (from *rake*). These effects indicate that the congruent and incongruent primes must have activated the semantic properties of the neighbor exemplars. As might be expected, a stronger form priming effect was obtained when the prime was a neighbor of the actual target word (e.g., *carnish-RADISH*). This type of priming can be thought of as relatively direct form of priming, in which the prime facilitates the *perception* of the target word, whereas the congruence conditions can be regarded as an indirect effect, in the sense that the prime has no direct relationship with the target, and affects only decisions about the target, not the perception of it.

These findings present a strong case for cascaded semantic activation, since the congruence effect must indicate that the semantic properties of the neighbor were activated strongly enough to influence the decision to the target. However, the fact that the primes were nonwords does allow for one possible counter-argument, and that is that the system recognizes that although there is no word that perfectly matches the prime *troctali*, it is nevertheless the case that *broccoli* is the best-matching category exemplar. It is possible that this amounts to the same thing as actually finding a perfect match, and it is only then that the semantic properties of the neighbor are activated, as a staged model might predict. Fortunately, there is a very simple way to test this argument. If the prime is a word rather than a nonword, then the closest match will be that word, and if its semantic properties are unrelated to either the positive or the negative category, then we should not expect to observe any congruence effect.

Experiment 2

This experiment is basically the same as the first, except that the primes are now words. It is here that the SCM similarity index becomes invaluable, since it lists all words that fall into the similarity range of 0.60–0.75 used in Experiment 1. Thus instead of trying to activate the semantic features of *cabbage* by using a nonword prime such as *cobbide*, a word prime such as *capable* (overlapping with *cabbage*) was used. Thus, *cabbage* could no longer be accepted as a best match for the prime, since a perfect match is available. Phenomenologically, these primes were very difficult to link to their corresponding target, despite their orthographic overlap. For example, while monitoring for city names, the link between a prime and the target is readily apparent in a neighbor pair such as *older-BOULDER*. However, the link is less obvious in such examples as the congruent pair *membrane-BOULDER* (*membrane* being a neighbor of *Melbourne*) or the incongruent pair *leisure-BOULDER* (*leisure* being a neighbor of *lettuce*).

Method

Participants

A total of 42 University of Arizona students from the same subject pool as Experiment 1 served as subjects in this experiment. None had participated in Experiment 1.

Materials and design

The categories in Experiment 2 were the same as in Experiment 1, but in different combinations: *profession* vs. *animal*, *vegetable* vs. *city*, *country* vs. *girl's name*, and *boy's name* vs. *tool*. The primes were again orthographically similar either to the target (neighbor condition), to a member of the target's category (congruent condition), or to a member of the opposing category (incongruent condition). As before, the measure of similarity was 0.6–0.75 SCM similarity (0.66 average). All items are listed in Appendix A.

Procedure

The procedure was identical to that of Experiment 1.

Results

The data from one subject who made more than 20% errors on the word targets were excluded. RTs on trials where an error occurred were discarded (8.37% of the data), as were any RTs that were less than 300 ms or greater than 1500 ms (0.41% of the data). The only significant effect in the error data was Prime type ($z = 2.17$, $p = .03$), with congruent items showing fewer errors. The mean reaction times and error rates in each of the various conditions are shown in Table 2.

As in Experiment 1, a linear mixed effects model was fitted, again with congruent primes and positive exemplar targets as the baseline. Once again, congruent items (542 ms) produced faster responses than incongruent items (553 ms). This difference was significant ($t = 3.11$). The only other significant effect was that exemplars were faster than non-exemplars ($t = 6.95$). Notably, there was no sign of any form-priming, since no significant difference was found between the congruent and neighbor prime conditions ($t < 1$) as had been found in Experiment 1.

Discussion

Using real words as primes did not eliminate the indirect priming effect, since congruent primes once again produced faster responses to the target than incongruent primes. Thus, it seems clear that a prime such as *capable* must activate the semantic properties of its neighbor *cabbage*, as a cascaded activation model would predict. However, a problem for this interpretation is that words are relatively ineffective as form primes in masked priming experiments (Davis & Lupker, 2006; Forster & Veres, 1998), and can in fact have an inhibitory effect on the target. In an

Table 2
Average reaction time (RT) in milliseconds and error rate for the semantic categorization task, according to type of target (positive exemplar, negative exemplar) and prime (congruent, incongruent, neighbor), where all primes are words. Priming effects are given with congruent primes as a baseline (Experiment 2).

Prime	Exemplars			Nonexemplars		
	Example	RT	%E	Example	RT	%E
Congruent	*capable-RADISH*	520	6.7	*older-SEATTLE*	565	8.5
Incongruent	*battle-RADISH*	529	9.5	*cart-SEATTLE*	577	9.6
Form	*radio-RADISH*	519	8.3	*battle-SEATTLE*	564	7.6
Congruence		9	2.8		12	1.1
Form priming		1	−1.6		1	0.9

Note: In this example, the positive category was VEGETABLE, negative category CITY NAME. capable = cabbage, battle = seattle, radio = radish, older = boulder, cart = carrot.

activation framework, this is attributed to the fact that when the target is presented, one of its major competitors has just been activated by the prime, which will then compete with the target. So, according to an activation model, the prime *capable* should suppress activation in the word unit for *cabbage*, which presumably would eliminate any cascaded semantic activation. Thus it is not surprising that the neighbor condition (direct priming) is no longer faster than the congruent condition, as it was in Experiment 1. This does not necessarily mean that there was no form priming effect at all (an unrelated baseline would be required to establish that), but it does at least indicate that the form priming effect in this experiment is weaker than it was in Experiment 1.

If anything, these results are even more provocative than those of Experiment 1, because on both theoretical and empirical grounds, it can be argued that word primes should be less likely to produce a congruence effect. Because of the surprising and unexpected nature of this effect, a further experiment was designed with new materials as a replication.

Experiment 3

This experiment is a replication of Experiment 2, using new materials. Once again, all primes were words.

Method

Participants

A total of 39 undergraduate students drawn from the same pool as in previous experiments served as participants, for which they received partial course credit.

Materials and design

The materials were similar to those in Experiments 1 and 2. Ten categories were chosen and juxtaposed as follows: Fruit/Vehicle, Bird/Musical Instrument, U.S. State/Color, Weather Phenomenon/Weapon, Insect/Article of Clothing. Additionally, a practice block contrasting the categories "a metal" and "a food flavoring" appeared before the test blocks, and the first three items of each block were counted as practice items and not included in the analysis. As in Experiments 1 and 2, no subject was informed beforehand that all the words not in the "yes" category were also in a category, nor what that category was. Real-word primes were chosen in the same manner as in Experiment 2. Average SCM similarity between form primes and their corresponding targets was 0.68, whereas the SCM similarity between targets and their congruent and incongruent primes was 0.17 (the same as random). Each of the 10 categories generated 12 items, so the total number of experimental items was 120, the same as in Experiments 1 and 2. The items are listed in Appendix A.

Results

No subjects made more than 20% errors. RTs on trials where an error occurred were discarded (7.02% of the data), as were any RTs that were less than 300 ms or greater than 1500 ms (1.08% of the data). There were no significant effects in the error data. Results are summarized in Table 3. A linear mixed effects model was again fitted to the reaction times of the participants with congruent primes and positive exemplar targets as the baseline. Positive exemplars were responded to faster than negative exemplars, $t = 3.77$, and congruent items were responded to faster than incongruent items, $t = 2.74$. As in Experiment 2, no significant difference was found between form primes and congruent primes ($t = 1.00$).

Discussion

The results of this experiment provide a close replication of the results of Experiment 2. There is a clear congruence effect with word primes, but once again, the direct form priming effect is not significant. As indicated earlier, the absence of a form priming effect may just reflect the fact that a congruent condition is not an ideal baseline. However, a form prime is necessarily a congruent prime, so a congruent baseline should be preferable to an incongruent prime, which is what a completely unrelated word would be. Thus it seems that the existence of a clear form priming effect is critical for the interpretation of the congruence effect as a consequence of cascaded semantic activation. If a word prime has the effect of suppressing activation in its neighbors, then it would seem to follow that cascaded semantic activation should also be suppressed.

There is one way to escape this conclusion. In the original formulation of the IA model (McClelland & Rumelhart, 1981), it was proposed that lexical competition would be delayed until a critical activation level had been reached.

Table 3
Average reaction time (RT) in milliseconds and error rate for the semantic categorization task, according to type of target (positive exemplar, negative exemplar) and prime (congruent, incongruent, form), where all primes are words. Priming effects are given with congruent primes as a baseline (Experiment 3).

Prime	Exemplars			Nonexemplars		
	Example	RT	%E	Example	RT	%E
Congruent	*fifth-VULTURE*	549	7.3	*gutter-TRUMPET*	584	6.2
Incongruent	*flake-VULTURE*	561	7.1	*future-TRUMPET*	594	8.3
Form	*future-VULTURE*	545	6.7	*tempt-TRUMPET*	579	6.5
Congruence		12	−0.2		10	2.1
Form priming		4	−0.6		5	−0.3

Note: In this example, the positive category was BIRDS, negative category MUSICAL INSTRUMENTS. fifth = finch, flake = flute, gutter = guitar, future = vulture.

Thus, for a brief time, there would be no competition between word units activated by the prime, and during that interval, the lexical status of the prime would be irrelevant. If cascaded semantic activation is generated during this interval, then it is possible that this activation persists even after activation in the corresponding word unit has been suppressed. The alternative would have to be that the competitive process operates at a semantic level as well as at a form level.

Experiment 4

Although the congruence effects are small, they appear to be reasonably reliable, especially when the prime is a nonword (Experiment 1). Apart from the absence of a strong direct form priming effect when the prime is a word, the results are exactly what a cascaded model would predict. However, a fundamental issue that has not been addressed in these experiments is the possible role that the categorization task itself may play. So far, we have assumed that the semantic properties of all neighbors are automatically activated, and that this activation is purely stimulus-driven. In addition, we have assumed that the categorization task is relevant only as a method of indexing this activation. However, it is possible that the categorization task itself plays a causal role, and the semantic properties of a neighbor are activated only if that neighbor happens to be an exemplar of the category. This could be described as *conditional* activation, whereas the cascaded model assumes *unconditional* activation. Thus, one could ask whether *capable* makes one think of *cabbage* only when the task is classifying words as vegetable names. Would the same effect occur with a different category? Would the same effect occur when there is no category?

In the following experiment, we attempt to eliminate the influence of the category by measuring semantic activation in a different way, using a two-alternative forced-choice (2-AFC) discrimination task, similar to that used by Marcel (1983). In this experiment, the prime is presented in the same way as in the earlier experiments, but the prime is backward masked by a random consonant string instead of a target word, which is then followed by two words presented side by side. The subject's task is to guess which of these alternatives is more similar in meaning to the prime. Thus, if the prime was *river*, the alternatives might be *ocean* and *carpet*, and the question is whether subjects would pick *ocean* more often than *carpet* when asked to guess which word was closer in meaning to the prime. One might argue that such a discrimination task is really just a measure of the degree of awareness of the prime (e.g., Kouider & Dupoux, 2004), ignoring the fact that subjects insist that they are simply guessing. Perhaps the clearest demonstration that subjects do have access to information about the prime, but are nevertheless unaware of its identity comes from masked priming experiments using a process-dissociation approach (Debner & Jacoby, 1994; Merikle, Joordens, & Stolz, 1995). These experiments estimate independently the influence of conscious and unconscious perception on responses in a stem completion task. The results show that with a 50 ms prime, subjects are unable to follow the instructions in the exclusion condition (not to use any word that had just been presented), but with a longer prime duration, they were able to follow this instruction. Debner and Jacoby concluded that "guessing" is in fact influenced by unconscious perception.

According to Marcel (1983), the masking procedure may simply eliminate any *visual* record of the prime, but leaves other forms of activation (orthographic, phonological, and semantic) intact. Viewed in this light, we could use the discrimination task as a method of indexing the semantic activation produced by words and their neighbors. The advantage of this technique is that when the prime is presented, no category information is provided at all. It is only after the prime has been processed that any information about how the prime should be categorized is given. Thus, we can now ask whether the prime *capable* makes one think of *cabbage* without any cue that the prime could be the name of a vegetable.

Method

Participants

A total of 32 University of Arizona students from the same subject pool as Experiments 1 and 2 served as subjects in this experiment. None had participated in either experiment.

Materials and design

A total of 80 items was constructed by combining a prime with a pair of alternative words. For 30 of these items, one of the alternatives was directly related in meaning to the prime, while the other was completely unrelated (e.g., prime = *dream*, alternatives = *square sleep*). In addition, a further set of 30 items was constructed by combining the same alternatives with a prime that was an SCM neighbor of a word that was related in meaning to one of the alternatives (e.g., prime = *cream*, alternatives = *square sleep*). In this case, the primes are indirectly related to one of the alternatives. The primes consisted of a mixture of primes taken from Experiments 1 and 2, plus a new set of words taken from an experiment by Gorbunova (2009), designed to avoid having multiple examples of words drawn from the same category. The neighbor primes were selected using the same criteria as used in Experiments 1 and 2, namely having an SCM similarity index between 0.60 and 0.75. Four counterbalanced lists of items were constructed. Counterbalancing for whether the correct alternative was on the left or the right was achieved by keeping the alternatives constant, but varying the prime. For example, a directly related item in List A with the correct alternative on the right (e.g., *writer – lion poet*) would appear in List B with a different prime, and the correct alternative now on the left (e.g., *tiger – lion poet*). The materials were also counterbalanced with respect to whether the prime was directly or indirectly related to one of the alternatives. Thus, List C contained an item with the same alternatives as an item in List A, but with a prime that was an SCM neighbor of the prime used in List A (e.g., *wither – lion poet*, where *wither* is a neighbor of *writer*), and List D contained an item with the same alternatives as in List B, but with a prime that was an SCM neighbor of the prime used in List B (e.g., *tower – lion poet*, where *tower* is an SCM neighbor of *tiger*). The critical items consisted of 60 such triples, each with a prime duration of 50 ms. A further 20 triples were included with a directly related prime presented for 100 ms, mainly in order to (a) provide some encouragement to the subjects, and (b) to assess whether the task was being carried out effectively. All items are listed in Appendix A.

Procedure

Each item consisted of the following sequence. The first frame was a 500 ms forward mask consisting of hash marks, equal in length to the prime. The second frame consisted of the prime in lower case, presented either for 50 or 100 ms. Immediately following, the third frame consisted of a random consonant string (in upper case) of the same length as the prime, which acted as a backward mask. Following this was a blank screen for 1000 ms, followed by the two alternatives side by side (in lower case). These remained on the screen until the subject responded by choosing either the left or the right alternative by pressing an appropriate response key. The instructions first explained the existence of the prime and the fact that sometimes it would be too brief for them to identify it, and that the task was to try guess which alternative was closer in meaning to the prime. Examples were given and 8 practice trials were included.

Table 4
Mean subject accuracy in the 2-AFC discrimination task with masked word primes that are directly or indirectly related to one alternative as a function of prime duration (Experiment 4).

Prime duration (ms)	Direct prime	Indirect prime
50	*listen – hear hour* *60.5%*	*loosen – hear hour* *49.8%*
100	*green – brown stove* *79.9%*	

Results

Table 4 shows the mean accuracy in each condition. Using a one-sample t test comparing the overall error rate in each condition with chance expectation (50%), it is clear that discrimination accuracy in the 100 ms Direct condition is better than chance, $t(31) = 10.33$, $p < .001$ by subjects, $t(19) = 16.14$, $p < .001$ by items. Performance in the Direct condition with a 50 ms prime is less accurate, but is still significantly better than chance, $t1(31) = 4.75$, $p < .001$; $t2(59) = 4.52$, $p < .001$. However, there is no evidence that discrimination accuracy in the Indirect condition was any better than chance, $t1(31) = 0.13$, $p = .89$; $t2(59) = 0.24$, $p = .81$.

Discussion

The results are clear-cut. There is no indication that a masked prime that is indirectly related (via a neighbor) to one of the alternatives has any systematic effect on which alternative is selected, whereas primes that are directly related do have a clear effect. We conclude that when the prime is processed without any target category in mind, a prime does not activate the semantic properties of its neighbors. This is not what a cascaded model would predict.

It could be argued that this conclusion applies only to subliminal primes. For example, what would happen if indirect primes had also been tested with a 100 ms prime? This condition was avoided on the grounds that if the prime was visible, it would be evident that neither of the alternatives was related in any way to the prime, which might then undermine the subject's confidence that the experiment was meaningful. A more important reason for not using a visible prime was that it would be identified and encoded into working memory, so that it would still be available when the alternatives were presented. This allows for the possibility that subjects might then attempt to use the alternatives as a potential context, which might then change the activation produced by the prime. For example, in the case of the indirect item *loosen – hear hour*, it is possible that *loosen* initially does not activate the semantic properties of *listen*, but when the subject attempts to relate it to the alternative *hear*, the activation changes. This could occur in the following way. The subject essentially asks how the meaning of *loosen* could be related to the meaning of *hear*. A related word for *hear* would obviously be *listen*, at which point the similarity of *loosen* and *listen* might be recognized, leading to a bias to select *hear* as the response. So in this case, the alternatives might begin to act in a similar way to a category in a semantic categorization task. However, if the prime is masked, and is unavailable to consciousness when the alternatives are presented, this possibility is avoided.

A very similar effect was observed in a pilot study we conducted using the semantic relatedness task developed by Hino et al. (2012). In that experiment, subjects were required to decide whether two sequentially presented Japanese words (both visible) were semantically related. The question addressed was whether a response conflict would be generated if the target word was orthographically similar to a word that was semantically related to the reference word. An English example would be *MISSILE-POCKET*. The results obtained by Hino et al. (2012) showed that responses to such items were slowed relative to a pair such as *SCHOOL-POCKET*. The interpretation was that the target word *POCKET* activated the semantic properties of its neighbor *ROCKET*, which then created a response conflict when the reference word was a related word *MISSILE*. Given the results of the current experiment, it would appear that the reference word *MISSILE* acts as a context, much like a category in a semantic categorization experiment. Adapting this technique to the current materials, we might expect to see a similar effect with pairs such as *LETTUCE-CAPABLE*, where the first word is a category exemplar, and the second word is a neighbor of another exemplar of the same category. In this case, *LETTUCE* could act in much the same way as the category VEGETABLE in a semantic categorization task. Under these conditions, a subset of the items used in Experiments 1–3 showed a reliable ($t = 3.99$) interference effect of 25 ms (i.e., "No" responses to items such as LETTUCE-CAPABLE were 25 ms slower than "No" responses to TABLE-CAPABLE). Further, the same effect was present when the order was reversed (*CAPABLE-LETTUCE*). Thus, when the reference word is visible, it exerts an effect whether it precedes or follows the neighbor.

This reasoning can also be applied to an experiment by Pecher, de Rooij, and Zeelenberg (2009), who used a sentence verification task with items such as *Can a pear growl?* The results showed slower "No" responses when the subject of the sentence was a neighbor of a word that did have the relevant property (i.e., *bear*). The critical feature of this experiment is that no explicit categorization task is involved. However, at some point, the question of the kinds of objects that can growl must arise, and bears, lions and dogs would be good examples. So the task requires a decision as to whether a pear belongs to the category of objects that typically growl, and hence the task is equivalent to a semantic categorization task. Because the critical word *pear* is visible, it will still be available when *growl* is processed, and it may only be at this point that the similarity of *pear* and *bear* becomes relevant. That is, when *pear* is initially processed, the lexical representation of *bear* is partially activated, but its semantic properties are not. It is only after *growl* has been processed that the semantic properties of *bear* become relevant.

Experiment 5

It is possible that the failure to obtain cascaded activation in the previous experiment was a result of using words as primes rather than nonwords. Nonword primes were used in Experiment 1, and the congruence effects observed in that experiment appeared to be stronger than when words were used in Experiments 2 and 3. Given the importance of the conclusion that cascaded activation is not observed without the influence of a category, and given that there are reasons to suppose that words would be less likely to generate strong cascaded effects, it was considered necessary to establish whether the same results are obtained with nonword primes. The following experiment uses exactly the same design and procedure as the previous experiment, the only change being that the indirect primes are now nonwords that overlap orthographically with a word that is related to one of the alternatives.

Method

Participants

A total of 32 undergraduate students drawn from the same pool as in previous experiments served as participants, for which they received partial course credit.

Materials

The design and materials were the same as in Experiment 4, except that the primes were nonwords rather than words. The nonwords were chosen to fall within the same SCM range as used in the previous experiments. The average SCM match coefficient was 0.69. The items are listed in Appendix A.

Results and discussion

The mean accuracy in each condition is shown in Table 5. Performance with a 100 ms Direct prime is again significantly better than chance, $t1(31) = 20.08$, $p < .001$; $t2(19) = 23.77$, $p < .001$. More importantly, with a 50 ms prime, performance was significantly better than chance with a Direct prime, $t1(31) = 8.33$, $p < .001$; $t2(59) = 8.57$, $p < .001$, but not with an Indirect prime, $t1(31) = 0.64$, $p = .52$; $t2(59) = 0.53$, $p = .59$.

Once again, the results are clear-cut. Without the prior context of a category, a masked prime does not activate the semantic properties of its neighboring words, regardless of whether the prime is a word or a nonword. However, the results for the direct prime condition are very similar to the corresponding conditions in Experiment 4.

Experiment 6

There is perhaps one final way to preserve the assumption of cascaded activation, and that would be to propose that although the indirect prime did activate the semantic

Table 5
Mean subject accuracy in the 2-AFC discrimination task with masked word and nonword primes that are directly or indirectly related to one alternative as a function of prime duration (Experiment 5).

Prime duration (ms)	Direct prime	Indirect prime
50	*listen – hear hour* *64.8%*	*masten – hear hour* *49.1%*
100	*green – brown stove* *88.6%*	

properties of its neighbors, this activation completely decayed by the time the alternatives were presented (1 s later). This is not the case for the direct prime, of course, but this could be attributed to differences in the strength of activation, with direct activation being much stronger than indirect (cascaded) activation, and hence longer lasting. The simplest way to test this hypothesis is to run the 2-AFC procedure again, but this time presenting the alternatives *before* the masked prime.

Method

Participants

A total of 20 undergraduate students drawn from the same pool as in previous experiments served as participants, for which they received partial course credit.

Materials

The items were the same as in Experiment 4 (word primes).

Procedure

Instead of presenting the alternatives 1 s after the masked prime, the alternatives were presented first, followed 2 s later by the masked prime sequence. The alternatives remained on the screen until the subject responded.

Results

The mean accuracy in each condition is shown in Table 6. Comparison with the results reported for Experiment 5 shows little change as a function of moving the alternatives forward in time, except perhaps for a slight improvement in accuracy in the Direct condition. As before, the 50 ms Direct prime condition is significantly better than chance, $t1(19) = 5.36$, $p < .001$; $t2(59) = 7.53$, $p < .001$, but this is not the case for the Indirect prime (both $ts < 1$). It seems clear that the poor performance in the Indirect prime condition in Experiment 4 could not have been a consequence of a rapid decay of activation.

Table 6
Mean subject accuracy in the 2-AFC discrimination task with masked word primes when the alternatives preceded the masked prime (Experiment 6).

Prime duration (ms)	Direct prime	Indirect prime
50	*hear hour – listen* 66.7%	*hear hour – loosen* 50.5%
100	*brown stove – green* 86.8%	

General discussion

Under the conditions of a semantic categorization task, there is clear evidence that both words and nonwords activate the semantic properties of their neighbors, as predicted by the assumptions of a cascaded activation model. It was already known that this effect occurs when the neighbor is visible (the *turple* effect, Forster & Hector, 2002, and the *hat* in *that* effect, Bowers et al., 2005) and it is now clear that this is also true when the neighbor is masked (Experiments 1–3). The important point to note is that this activation occurs despite the use of a much lower level of orthographic overlap than normally used to define an orthographic neighborhood. The consequence of this is that the neighbor prime is not simply the nearest word to an exemplar of the category; rather, there are many neighbors that are more similar to an exemplar than the primes used in these experiments. It should also be noted that this activation occurs under conditions that would not be favorable for cascaded activation, namely when the prime is a word.

However, the results of the two-alternative discrimination task (Experiments 4–6) show that the cascaded activation effect depends crucially on the context provided by the categorization task itself. When the subject's task is to decide whether the masked prime is related semantically to a subsequently presented word, there is no evidence for a cascaded activation effect, regardless of whether the prime is a word or a nonword. The most natural inference from this result is that semantic activation is not normally cascaded.

This leads us naturally to the next question: what is it about the categorization task that produces cascaded activation? One possibility is that the category preactivates the word units for all exemplars of the category (for similar proposals, see Jared & Seidenberg, 1991; Monsell, Doyle, & Haggard, 1989). This activation, when combined with the weak activation produced by the neighbor prime, is sufficient to reach threshold, which then triggers the semantic activation process and produces the response conflict observed in Experiments 1–3. Thus, the semantic properties of the prime's neighbors are only activated if the neighbor is an exemplar of the category. When the influence of the category is removed, the weak activation produced by the prime alone is not sufficient to trigger semantic activation of the neighbors of the prime.

The computational problem faced here is how to establish the intersection of two sets. To take an actual example, on a given trial the subject's task might be to determine the intersection of the set of city names and the set of words that are orthographically similar to the word *membrane* (an SCM neighbor of *Melbourne*). Logically, this requires enumeration of the members of one set, and then checking whether any member is also a member of the second set. This means that two items of information need to be available simultaneously: (a) whether a given word is a candidate for the current stimulus (i.e., whether it has sufficient orthographic overlap with the prime), and (b) whether the candidate is a member of the category. If both conditions are satisfied, then the semantic properties of the candidate are activated. However, given that the number of items in either set in the above example is fairly substantial, this seems an almost intractable task.

An alternative to a category pre-activation account is to propose that when the task is semantic categorization, the threshold for a partial match is lowered for all words regardless of category membership. So, for example, all words with an SCM match coefficient of at least .60 (or perhaps even lower) with the prime become candidates. The candidates are then scanned to see whether an exemplar of the category is present. If one is detected, that candidate is selected for further processing, which involves activating its semantic properties, and if category membership is confirmed, a spelling check is carried out. Note that there is a conundrum here. In order to decide whether to activate the semantic properties of a candidate, the system needs to know what those properties are.

The difference between this approach and category pre-activation is the same as the difference between a prospective and a retrospective account of semantic priming (Forster, 1981; Neely, Keefe, & Ross, 1989). In a prospective account, an attempt is made to predict the target word in advance, which involves activating all words that are related to the prime. This is essentially what the category pre-activation process does. However, in a retrospective semantic matching account, no attempt is made to predict the target, but preference is given to candidates that are semantically related to the prior context.

It should be noted that the relationship between the neighbor of the prime and the related alternative in the 2-AFC discrimination experiments was not necessarily one of category and exemplar. Occasionally they were related in this way (e.g., *writer* – *poet*), but more often they were either similar in meaning (*alive* – *dead*), or associates (e.g., *judge* – *court*). This difference may be important, especially for the category pre-activation interpretation: whereas the category FRUIT might pre-activate all members of the category, it might not be the case that the word APPLE would have the same effect. Further research is needed to establish whether the nature of this relationship is critical. An obvious experiment would be to run the 2-AFC discrimination task with categories as the alternatives rather than related words (e.g., prime = *membrane*, alternatives = CITY FRUIT).

It is worth noting that the categorization task also plays a crucial role in other phenomena involving masked priming. In a cross-language translation priming experiment, individuals who learned a second language relatively late show little or no translation priming in a lexical decision task from primes in the second language to translation equivalent target words in the native language, although there is strong priming in the reverse direction (e.g., Gollan, Forster, & Frost, 1997). However, when the task is semantic categorization, priming from the second to the first language is obtained, but only for exemplars of the category (Finkbeiner, Forster, Nicol, & Nakamura, 2004; Wang & Forster, 2010). Finkbeiner et al. interpreted this effect as showing that the category acted as a kind of filter, suppressing secondary senses of the word that are unlikely to be shared across languages, and thereby increasing the semantic overlap between prime and target. Similar results were obtained by Xia and Andrews (2015), who argued that the category boosts the capacity of masked L2 words to activate their conceptual representations, which is equivalent to the category preactivation account. However, more recently, De Wit and Kinoshita (2015) have argued against a spreading activation account of priming by showing that the same prime–target pairs that fail to show masked semantic priming in a lexical decision task (with a 50 ms prime duration) nevertheless show strong priming in a semantic categorization task. They suggest that the requirement to categorize the target word fundamentally alters the way in which both the prime and the target are processed.

It should be noted that these results also provide very strong support for the validity of the SCM measure of word similarity. We deliberately chose a relatively low similarity range to avoid the possibility that the discrepancy between the prime and its neighbor was simply overlooked, which could have been the case if we had used one letter different substitution primes. The fact that reliable effects can be obtained with such a low degree of overlap is very surprising, and it is possible that even lower similarity values could be used. It also suggests that SCM measures should be used in any experiment that claims to hold orthographic overlap constant, while varying either phonological or morphological similarity.

Finally, a comment about prime awareness. In this article, we have taken the position that the 2-AFC semantic discrimination task measures the degree of semantic activation produced by the prime, i.e., it reflects the process that is responsible for priming. However, the literature on masked priming contains many examples in which similar 2-AFC tasks have been used to test for awareness of the prime (e.g., Finkbeiner et al., 2004; Kouider & Dupoux, 2004). One might therefore be tempted to infer that the above-chance accuracy in the discrimination experiments demonstrates partial awareness of the primes. This seems an unreasonable position to take, since it is virtually equivalent to arguing that any behavioral effect of the prime is ipso facto evidence of awareness of the prime (e.g., Eriksen, 1960). Also, it ignores the phenomenological report of subjects, who insist that they were simply guessing. A better way to establish awareness might be to use a test of the availability of purely *visual* aspects of the prime, properties which are totally independent of the lexical properties of the prime, on the assumption that the backward mask erases the visual record of the prime, but not any higher-level properties. If subjects can reliably discern properties such as the font that was used for the prime, or whether the prime was in italics or not, then perhaps one might conclude that they were aware of the prime (i.e., they could remember seeing the prime). Nevertheless, this issue is not critical for the current study, since none of the conclusions depend on the assumption that there was no conscious awareness of the prime.

In conclusion, the current findings show that the apparent activation of the semantic properties of a masked word and all its neighbors is a task-dependent phenomenon. Neighbor activation occurs when the task requires categorization of a visible target, but not when there is no such requirement. This latter result is compatible with a staged approach to lexical access, which argues that semantic activation is delayed until the stimulus is resolved at the level of form. To explain the problematic findings from the semantic categorization experiments, one could appeal to a spreading activation account in which category preactivation combines with weak stimulus-produced activation to reach threshold, or to a retrospective account, in which only the neighbors that are exemplars of the category are activated. Current findings do not provide any basis for choosing between the prospective and the retrospective accounts of the category effect. However they do open up an avenue for investigation of several issues in addition to the existence of cascaded activation, such as the role of distributional statistics, and the nature of the categorization process itself.

Appendix A

A.1. Stimuli used in Experiment 1

The prime is listed first, followed by its neighbor, and the SCM match index.

Professions.

kanader (manager) 0.67; pawyer (lawyer) 0.75; sebretart (secretary) 0.73; trofestor (professor) 0.73; ashlope (athlete) 0.67; farpelter (carpenter) 0.73; accoultang (accountant) 0.67; engipees (engineer) 0.7; nerge (nurse) 0.71; bufinessmap (businessman) 0.77; mentint (dentist) 0.67; dinitor (janitor) 0.67; leapher (teacher) 0.67; fook (cook) 0.67; bansar (banker) 0.75; dontog (doctor) 0.62; polivemad (policeman) 0.73;

Cities.

parim (Paris) 0.71; dabeigh (Raleigh) 0.67; bailmer (Boulder) 0.67; bartimorn (Baltimore) 0.73; greelsbarg (Greensboro) 0.67; biami (Miami) 0.71; soittre (Seattle) 0.67; wetrait (Detroit) 0.67; nallas (Dallas) 0.75; thicogo (Chicago) 0.67; houspop (Houston) 0.67; withingson (Washington) 0.75; shiladerphia (Philadelphia) 0.79; boptoy (Boston) 0.62; lonsod (London) 0.66; tharlosse (Charlotte) 0.64; lenver (Denver) 0.75;

Vegetables.

sarrot (carrot) 0.75; beaf (bean) 0.67; cusunder (cucumber) 0.7; bettune (lettuce) 0.67; cobbide (cabbage) 0.67; camish (radish) 0.62; tomapa (tomato) 0.62; burnip (turnip) 0.75; lucchibi (zucchini) 0.7; nepper (pepper) 0.75; fotato (potato) 0.75; carliglowes (cauliflower) 0.69; troctoli (broccoli) 0.7; pel (pea) 0.6; belery (celery) 0.75; jeet (beet) 0.67; lorn (corn) 0.67;

Countries.

bapan (Japan) 0.71; casapa (Canada) 0.75; cussia (Russia) 0.75; efghagistan (Afghanistan) 0.7; entlord (England) 0.67; fritoin (Britain) 0.67; grance (France) 0.75; nerminy (Germany) 0.67; melimo (Mexico) 0.75; iremang (Ireland) 0.67; isoly (Italy) 0.71; idreel (Israel) 0.75; ilfia (India) 0.71; grooce (Greece) 0.75; ogypt (Egypt) 0.71; oraq (Iraq) 0.67; orgencina (Argentina) 0.73;

Girl's names.

ginda (Linda) 0.71; resecco (Rebecca) 0.67; tary (Tara) 0.67; saram (Sarah) 0.71; autump (Autumn) 0.75; indroa (Andrea) 0.62; halty (Holly) 0.71; zicore (Nicole) 0.62; shaili (Sheila) 0.63; sutun (Susan) 0.71; tinu (Tina) 0.67; luth (Ruth) 0.67; ilice (Alice) 0.71; biane (Diane) 0.71; bete (Beth) 0.67; shirro (Sherry) 0.62; rophel (Rachel) 0.75;

Boy's names.

fosaph (Joseph) 0.62; rict (Rich) 0.67; blean (Brian) 0.71; seffroy (Jeffrey) 0.67; justil (Justin) 0.75; puan (Juan) 0.67; luin (Luis) 0.67; reorge (George) 0.75; ulex (Alex) 0.67; rasiel (Daniel) 0.62; koath (Keith) 0.71; oaron (Aaron) 0.71; erib (Eric) 0.67; borty (Barry) 0.71; motheal (Michael) 0.72;

Tools.

drilk (drill) 0.71; moy (mop) 0.6; broop (broom) 0.71; trawem (trowel) 0.62; axo (axe) 0.6; boe (hoe) 0.6; trush (brush) 0.71; wremph (wrench) 0.75; thovel (shovel) 0.75; taw (saw) 0.6; ledor (lever) 0.71; raka (rake) 0.67; knole (knife) 0.71; cliers (pliers) 0.75; famter (hammer) 0.62;

Animals.

geer (deer) 0.67; poat (goat) 0.67; wolk (wolf) 0.67; torse (horse) 0.71; tigel (tiger) 0.71; moust (mouse) 0.71; bebra (zebra) 0.71; mooso (moose) 0.71; theep (sheep) 0.71; rabbig (rabbit) 0.75; dolken (donkey) 0.63; lidart (lizard) 0.63; furtle (turtle) 0.75; niroffe (giraffe) 0.67; theeteh (cheetah) 0.56.

A.2. Stimuli used in Experiment 2

Professions.

book (cook) 0.67; maker (miner) 0.71; nose (nurse) 0.68; post (pilot) 0.64; anger (banker) 0.62; faster (farmer) 0.75; larger (lawyer) 0.75; senior (sailor) 0.72; bother (butcher) 0.72; monitor (janitor) 0.67; manner (manager) 0.72; winter (painter) 0.67; older (soldier) 0.61; dinner (designer) 0.63; center (carpenter) 0.64;

Animals.

year (bear) 0.67; door (deer) 0.67; get (goat) 0.62; hook (hawk) 0.67; cruel (camel) 0.71; home (horse) 0.68; loose (moose) 0.71; house (mouse) 0.71; shop (sheep) 0.68; tower (tiger) 0.71; shale (whale) 0.71; choose (coyote) 0.72; hazard (lizard) 0.62; part (parrot) 0.66; title (turtle) 0.72;

Vegetables.

sea (pea) 0.6; born (bean) 0.67; boat (beet) 0.67; can (corn) 0.62; union (onion) 0.71; cart (carrot) 0.66; every (celery) 0.62; graphic (garlic) 0.75; upper (pepper) 0.62; photo (potato) 0.65; radio (radish) 0.62; trip (turnip) 0.65; capable (cabbage) 0.72; league (lettuce) 0.64; partly (parsley) 0.75;

Cities.

chair (Cairo) 0.68; brain (Berlin) 0.72; deals (Dallas) 0.65; danger (Denver) 0.75; fresh (Fresno) 0.62; marked (Madrid) 0.72; slow (Moscow) 0.5; music (Munich) 0.62; page (Prague) 0.68; train (Tehran) 0.65; rich (Zurich) 0.62; bring (Beijing) 0.59; older (Boulder) 0.64; phone (Phoenix) 0.61; battle (Seattle) 0.67;

Countries.

club (Cuba) 0.62; ran (Iran) 0.67; per (Peru) 0.67; crime (Chile) 0.71; cargo (Congo) 0.71; eight (Egypt) 0.68; idea (India) 0.68; nasal (Nepal) 0.71; pain (Spain) 0.71; face (France) 0.65; green (Greece) 0.62; serial (Serbia) 0.68; sudden (Sweden) 0.75; dark (Denmark) 0.56; island (Ireland) 0.75;

Girl's names.

ale (Anne) 0.62; bet (Beth) 0.67; alone (Alice) 0.71; belt (Betty) 0.57; dare (Diane) 0.68; evil (Emily) 0.57; honey (Holly) 0.71; media (Maria) 0.71; agenda (Amanda) 0.66; arena (Andrea) 0.65; alloy (Ashley) 0.59; define (Debbie) 0.72; singer (Ginger) 0.75; racial (Rachel) 0.75; shield (Sheila) 0.68;

Boy's names.

arm (Adam) 0.62; drag (Doug) 0.67; vary (Gary) 0.67; gate (Gene) 0.67; jail (Joel) 0.67; dark (Mark) 0.67; brown

(Brian) 0.71; broke (Bruce) 0.71; than (Ethan) 0.71; jury (Jerry) 0.68; vein (Kevin) 0.64; scene (Steve) 0.71; since (Vince) 0.71; dance (Daniel) 0.62; enemy (Jeremy) 0.62;

Tools.

axis (axe) 0.6; toe (hoe) 0.6; hop (mop) 0.6; cake (rake) 0.67; room (broom) 0.71; birth (brush) 0.68; dull (drill) 0.68; nice (knife) 0.57; fever (lever) 0.71; river (ruler) 0.71; harder (hammer) 0.75; powers (pliers) 0.75; hotel (shovel) 0.62; vowel (trowel) 0.62; ranch (wrench) 0.62;

A.3. Stimuli used in Experiment 4

The two Direct primes are listed first, followed by the two Indirect word primes, then the two alternatives.

Prime duration 50 ms.

lamb mouth lamp mirth sheep nose; white answer waste anger black question; listen minute loosen mingle hear hour; bad big bud beg nice tiny; shallow friend hollow frigid deep enemy; animal thought airmail tonight idea zoo; organ rash ordain cash piano itch; door guitar dear gutter window banjo; food tree fend free acorn eat; question forever section foyer answer always; night north might ninth day south; dentist peanut enlist planet doctor butter; empty chair employ chain full table; copper biscuit camper circuit zinc cracker; typhoon gold tycoon golf wind nickel; dress novel press oval blouse story; tiger writer tower wither lion poet; desire alive decide olive want dead; horse shoe home shop donkey sock; woman feel omen fuel man touch; missile ferry mobile forty rocket boat; war day wear dry battle week; venom nun venous fun poison priest; ohio cherry onion clergy florida grape; phone food pope find call order; daughter summer danger slumber son winter; husband cause disband curse wife effect; speed judge send jungle fast court; leak child beak chilled adult drip; india apple idea amble france pear; circle dream curdle cream square sleep; thumb tickle thug twinkle hand laugh; emotion supper mention slipper feeling dinner; stone queen stove queue rock king; eagle beetle exile bottle hawk spider; college squirrel allege shrivel school nut; knife jacket kite bucket sword sweater; street lonely strict loudly road alone; mustard river bastard rivet spice ocean; short slow shout low long fast; decision similar precision simmer choice alike; first peace frost page last war; law work lawn walk order job; cents error cells horror dollars mistake; roll fat poll feat weight bread; rain sparrow gain sorrow snow pigeon; near see bear sue distant view; nurse weird noise wind doctor strange; tiger tuba tower scuba bear trombone; noun palm neon calm verb hand; small month shell mirth large year; picture flower pickle slower painting rose; early enemy clearly energy late friend; dirty finger dusty ginger clean hand; taxi purple toxic purse truck green; sugar pistol super patrol salt rifle; minutes follow mines hollow hours lead; author winter anchor wander writer summer; father bottom farmer button mother top; native marriage notice massage indian divorce;

Prime duration 100 ms.

hip loud chip cloud bone voice; green oven greet over brown stove; acid arctic avoid tactic cold rain; front exit foot exist back enter; stand future spend futile sit past; peach nevada pinch nebula nectarine Michigan; boy toe body tone girl nail; coffee lizard coffin hazard tea snake; dagger shirt diaper shire spear coat; grass pool gears pail water green; dog pilot dot pint pet plane; judge child juggle chilled court baby; ache game cache fame pain play; lettuce robin league roman salad bird; freezer yellow fresher elbow refrigerator pink; ballet artist wallet arrest dance painter; book lemon bank demon novel vinegar; touch hours truth hairs feel minutes; least want east what most desire; brush width gush watch hair length;

A.4. Stimuli used in Experiment 5

The Direct primes and the alternatives were the same as in Experiment 4. The Indirect primes were as follows.

Prime duration 50 ms.

lonb morch; chite onsler; masten milate; zad bim; scoltow griond; aniol troght; orlin arsh; foor guibor; dood treo; queltior farvear; nocht nath; fenlist peoput; umpty cloir; calper niscoit; tychook golm; cress nebel; tigel wrober; dobire olave; herne slie; wolin meel; mostile furty; sar fay; cenom num; oluo chorty; pheme nood; douther selmer; lustand couze; spoad mudge; seak thild; ilfia apled; marcle dreap; chumb tuckel; elomian subber; stape quoan; eigre seefle; bollage squottel; knote jocker; stroat lomaly; mostart ravor; sturt spaw; demusian fimilar; first poade; maw wulk; calts ertar; boll wat; bain sporrot; lear dee; nelse woild; tigep muba; poun falm; spoll meath; pactole floker; eorty eleny; doaty fangel; paxi tarple; sulor postor; moniles bollow; anthar minter; focher bollom; notire mortioge.

Prime duration 100 ms.

chip cloud; greet over; avoid tactic; foot exist; spend futile; pinch nebula; body tone; coffin hazard; diaper shire; gears pail; dot pint; juggle chilled; cache fame; league roman; fresher elbow; wallet arrest; bank demon; truth hairs; east what; gush watch.

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