The Microgenesis of Priming Effects in Lexical Access

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The implications of priming experiments for a structural theory of the mental lexicon depend critically on the development of an adequate theory of the mechanics of priming. Masked priming techniques may simplify this task, since consciously perceived relationships play no role in masked priming. The implications of adopting an activation-based approach to morphological priming is discussed, and an alternative model is described.

Key Words: word recognition; masked priming; lexical access.

The study of word recognition leads down two paths. One leads toward the goal of understanding the structure of the mental lexicon, what is represented in it, and how it is acquired. The other path leads toward an understanding of the mechanics of lexical access. Is retrieving information from the lexicon like using a spreadsheet or is it better described in neural network terms? Do the effects of variables such as word frequency or morphological structure on access time tell us something about the way lexical information is organized or do they merely index the strength of the connections between orthographic and semantic nodes?

These two goals are distinct, but interdependent. Only limited progress in understanding structural aspects is possible if we ignore functional issues. The research to be discussed here may serve as an illustration. This work concerns the microgenesis of priming—a millisecond-by-millisecond account of the way in which priming takes place. As the general shape of the theory emerges, one can see that it may have consequences for purely structural issues.

WHAT IS PRIMING?

Priming occurs when the processing of a word (the target) is facilitated by a preceding stimulus (the prime). The most common interpretation of...
priming is that the cortical representations of the prime and target are interconnected or overlap in some way such that activating the representation of the prime automatically activates the representation of the target word. The most common application of this type of thinking is the spreading activation theory of semantic and associative priming, which assumes that the prime preactivates the representations of every word that is semantically or associatively related to it. The sentential version of this theory assumes that the prior context of a sentence fragment activates the representations of every word that could continue the sentence appropriately. This is a prospective theory of priming; the effect of the priming context is assumed to take place prior to presentation of the target.

An alternative interpretation is that the initial processing of the target word is quite unaffected by the prior context, but the process of responding to the target depends on how readily it can be meaningfully integrated with the prior context (e.g., see Neely, 1991; Forster, 1981). This is a retrospective theory of priming. Priming occurs postaccess, and it occurs when a link is established between the context and a possible analysis of the target stimulus, indicating that this candidate analysis is likely to be correct. This link may be an already-existing property of the lexicon (e.g., the associative link between the words bread and butter) or it may be a link established on-line by high-level cognitive processes having access to a very wide range of non-linguistic information (e.g., the currently topical link between the word impeach and the word House). In addition to providing confirmation, the link may also simplify the decision process. In a lexical decision experiment, for instance, the decision rule becomes “If target is related in meaning to context, respond Yes’” and this might be a much easier rule to follow than “If target has a meaning, respond Yes.’”

On a retrospective analysis, priming might not be all that informative about the structure of the lexicon. Thus, in a lexical decision experiment examining morphological priming, it could be the case that priming occurs because the representations of these two words overlap in some way or because the perceived relationship between these words simplifies the decision rule. This ambiguity would not matter if we could assume that the perception of a relationship automatically implied overlapping representations, but obviously this cannot be simply assumed. To avoid this problem of interpretation we have to devise special techniques. The method we use is to present the prime so briefly that the subject is quite unaware of its existence. Under these conditions, priming cannot be the product of any perceived relationship between the target and the prior context, since the subject is unaware that any context exists. This is the procedure developed by Forster and Davis (1984). A forward mask consisting of hash marks (#####) or an unrelated word is presented for 500 ms, followed by the prime in lowercase letters for 40–60 ms. Then follows the target stimulus in capital letters, again for 500 ms.
Despite the fact that subjects are unaware of the prime, it nevertheless has a strong effect. The strongest form of priming is identity priming (e.g., attitude–ATTITUDE), which is usually around 50 ms. Next comes form-priming, which typically involves a one-letter-different prime (e.g., aptitude–ATTITUDE). Priming effects here are usually around 30 ms. Both of these effects are assessed relative to a baseline condition in which the prime differs from the target at all letter positions (e.g., harmless–ATTITUDE). Other types of priming obtained with this technique include morphological priming (e.g., sent–SEND), which often (but not always) produces a small increment over and above what could be expected on the basis of similarity of form (Frost, Forster, & Deutsch, 1997; Grainger, Colé, & Segui, 1991). In addition, strong cross-language translation priming is obtained even when completely different scripts are used, e.g., Hebrew and English (Gollan, Forster, & Frost, 1997). These results demonstrate that priming is not just a reflection of orthographic or phonological overlap. Nor is it purely a function of semantic overlap, since masked semantic priming effects are surprisingly weak (e.g., Perea & Gotor, 1997).

**DOES PRIMING DEPEND ON AWARENESS OF THE PRIME?**

Much of the early work on priming found that it was very difficult to obtain form-priming (e.g., culture–VULTURE). However, this work always involved visible primes. Eventually, it was discovered that if the prime was masked, strong form-priming could be obtained (Forster, Davis, Schonbeck, & Carter, 1987). Subsequently, Forster and Veres (1998) went on to show that awareness was critical only if the prime was a word. If it was a nonword (e.g., nulture–VULTURE), then priming occurred whether the prime was visible or not. The suggested interpretation is that form-priming depends on the fact that the masked prime has not been successfully resolved. A word prime that we are aware of has been resolved in the sense that all alternative interpretations of the stimulus have been rejected. But if awareness is prevented, these alternative analyses are still active, and therefore form-priming can occur. Nonword primes cannot be fully resolved, and therefore they can prime words with similar form regardless of awareness.

This process of resolution corresponds quite closely to the notion of interlexical competition developed in localist network models such as the Interactive Activation Model (McClelland & Rumelhart, 1981). Initially, a stimulus activates many different lexical units, but these compete with each other. Eventually, only one unit survives, and this is the point of resolution. According to this model, the reason that there is no priming for culture–VULTURE when the prime is visible is that the prime has been resolved, which means that the activation in the unit for vulture (produced by the prime) has been driven down to resting level before the stimulus VULTURE is presented. However, if VULTURE is presented before this process is completed, priming will result.
This explanation implies that nonwords would always be better form-primes than words, even when masked. The reason is simply that a related word prime will compete more vigorously with the target than will a related nonword prime. Whether this prediction is correct or not is currently a matter of dispute (e.g., Ferrand & Grainger, 1992; Forster & Veres, 1998). Surprisingly, this appears to depend on the difficulty of the word–nonword discrimination required in a lexical decision task (Forster & Veres, 1998). If the nonword distractors are very similar to words (e.g., UMBROLLA), then the competitive model makes the correct prediction—there is no form-priming with words as primes. However, if the nonword distractors differ from a word by two letters (e.g., AMBROLLA), then equally strong priming is obtained for both word and nonword primes. One way to explain this result might be to argue that subjects use different criteria for making a lexical decision, as in the model proposed by Jacobs and Grainger (1992). When the discrimination is easy, decisions are based on summed activation over all word units, and simulations show that the expected priming is equivalent for word and nonword primes (Forster & Veres, 1998). But when finer discriminations are required, the summed activation criterion is abandoned, and the decision is based on local activation levels within single-word units. Under these conditions, simulations indicate that word primes produce less priming than nonword primes. An alternative view is that nonwords such as UMBROLLA are so close to words that they force the subject to adopt a very conservative approach. When it is discovered that the target apparently matches two closely related but different words (one match being generated by the prime, the other by the target), then a reanalysis of the target stimulus is triggered. This reanalysis begins from scratch, and since the prime is no longer present, the new analysis will not be influenced by the prime. This would eliminate priming when the prime is a word, but not when it is a nonword, since only one match is generated on these trials.

THE ACTIVATION METAPHOR

Most current attempts to understand lexical processing make use of the concepts of competition and activation borrowed from the original Interactive Activation Model (e.g., Marslen-Wilson, Tyler, Waksler, & Older, 1994). This model provides a flexible framework for describing how words interact with each other, but it brings with it a set of assumptions that need to be made explicit. For example, take the case of morphological priming. To test whether there is priming for pairs such as sent–SEND, it is customary to compare performance on such items with control pairs such as tent–TEND, which have the same degree of orthographic and phonological overlap. This precaution is essential since otherwise the priming effect could be attributed to form overlap alone. The logic underlying this assumes that any priming due to morphological overlap will sum with the priming due to form
overlap. But suppose this is not the case. Suppose that the observed priming effect is equal to whichever effect is the strongest. This would make it very difficult to observe morphological effects under conditions where form-priming is strong, and this in turn could lead to the incorrect conclusion that morphological effects do not exist under these conditions. Moreover, as we have seen, the outcome of such an experiment might depend on the type of nonword distractors used. If they are very close to an actual word, then form-priming should be weak or nonexistent, since the prime is necessarily a word. This will allow the underlying morphological effect to emerge (i.e., tent–TEND will not show priming, but sent–SEND will). But if the distractors are more distant from any word, then form-priming will be stronger, which will make it harder to detect the morphological effect. This state of affairs would give rise to an exceedingly complex set of interactions.

Informal discussions with other investigators working on masked morphological priming in English suggest that priming effects seem to come and go on an apparently random basis. This contrasts sharply with the situation in Hebrew (Frost, Forster, & Deutsch, 1997; Deutsch, Frost, & Forster, 1998), where morphological effects are remarkably stable. This might just indicate that English and Hebrew differ in the importance of morphology, but it could also be due to the fact that in Hebrew the orthographic overlap between morphologically related words is low relative to English. Therefore there will be less form-priming in Hebrew and morphological effects should be detected more reliably. In contrast, morphological effects in English may be detectable only when the experimental conditions happen not to favor form-priming. The relevant conditions may include the type of nonword distractors used (as suggested above) and also other factors such as the number of orthographic neighbors of the target (the more there are, the less form-priming will occur) and the duration of the prime (the longer the prime, the more resolution will occur and hence the less form-priming).

HOW TO EXPLAIN PRIMING EFFECTS

For various reasons, it seems most unlikely that masked priming reflects sublexical processes. Cross-script priming is just one piece of evidence that favors this assumption (for a discussion of the arguments both for and against a sublexical account of masked priming see Forster, 1998). A more plausible site is during the access/activation process itself. This is the most obvious site for an activation model, since the prime must activate the node for the target, and this activation must persist during the transition from the prime to the target so that the target node begins at a higher activation level than its normal resting level. However, this effect should be greater for low-frequency words than high-frequency words since low-frequency words have a much lower resting level. Very similar arguments apply in the case of a search model, where the equivalent assumption would be that the effect of
the prime is to shorten the search path to the target in some way or to some-
how make it possible to traverse the path more rapidly (the so-called
‘‘greased path’’ theory of priming). Since the search path is assumed to be
longer for low-frequency words, the effect should be greater for these words,
and therefore the effect should interact with frequency. However, masked
priming effects are the same for high-frequency as for low-frequency words
(Forster & Davis, 1984; Rajaram & Neely, 1992), which is very difficult to
explain, especially since the effects of long-term priming do show the ex-
pected interaction with frequency.

One solution to this dilemma is to postulate some additional process that
takes place after an entry has been accessed. This is designated an entry-
opening process (Forster & Davis, 1984). The idea is that the prime changes
the state of the target entry so that when the process initiated by the target
eventually arrives at the same entry (unaided by the prime), information can
be extracted more rapidly from the entry. So the priming effect only takes
place after the correct entry for the target has been located.

Essentially, priming is seen as a savings effect. This account makes a
strong prediction. The priming effect ought to be equal to the duration of
the prime (assuming that the target appears immediately after the prime).
So, if the prime duration is 30 ms, then the priming effect should equal 30
ms no matter how long it takes to open an entry. To see that this is the case,
consider how long it would take to pass from one room to another through
a door that took 30 s to unlock. If an accomplice unlocks the door well in
advance, then a full 30 s is saved, but if the accomplice only begins to unlock
it 10 s before you reach the door, then you can only save 10 s. On the other
hand, if it took only 5 s to unlock the door, then you could never save any
more than 5 s.

Figure 1 shows some data that provides support for this model (Forster &
Guess, 1996). This figure plots the amount of priming as a function of the
duration of the prime. Each curve represents data from a different experiment
in which prime duration was varied. The dotted curve represents data from
a single subject, while the other two curves are group data. It can be seen
that the curves are close to linear and the points are not far from a line with
a slope equal to 1. Interestingly, the growth in priming reaches an asymptote
somewhere around 60 ms, suggesting that it takes about 60 ms to open an
entry.

The Entry Opening Model involves two stages of processing. The initial
stage is a fast, frequency-ordered search process that compares a coded de-
scription of the input stimulus with each target entry. This process is so fast
that it cannot determine whether any entry exactly matched the input, but it
is capable of deciding whether it was a very close match (VCM) or a close
match (CM). Each entry that falls into either of these categories becomes a
candidate entry and is immediately scheduled for entry opening. When the
entry has been opened, a flag is set, but no further processing of that entry
FIG. 1. Amount of priming as a function of prime duration. The dotted curve represents data from a single individual tested on multiple occasions. The solid lines represent data from two separate experiments using group data. Note that the slopes are close to 1 and that the amount of priming appears to reach a maximum at about 60 ms prime duration.

It is possible until the flag has been set. The second stage of processing is a verification stage, which involves extracting information from the newly opened entry for each candidate and evaluating whether it is a suitable match. This model interprets form-priming as a case in which the entry for the target word was a CM for the prime stimulus and identity priming as a case in which it was a VCM for the prime stimulus.

This process is essentially equivalent to a two-stage filter. To find an entry that exactly matches the input, a very fine filter is required. However, a fine filter is very slow, and it would be too time-consuming to apply this filter to every entry in the lexicon. So instead, a coarse filter is used to remove unlikely candidates first. This is a very rapid process and can be used much more economically on a wide set of candidates.

How does this model explain the absence of form-priming when subjects

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1 This proposal is very similar to the activation–verification model of Paap, Newsome, McDonald, and Schvaneveldt (1982). The critical differences are that the initial stage of the activation–verification model is a parallel activation system rather than a sequential search and that frequency effects arise in the secondary verification stage rather than in the initial stage.
are aware of the prime? Once a match has been found, the entries for the invalid candidates are closed down (Forster & Veres, 1998). If the duration of the prime is long enough for awareness to occur, this closing-down process is more likely to have been completed, which means that the entry for the target will have been returned to its original unprimed state. But with a very short prime duration, the entry for the target may still be open, which will produce a savings. Of course, if the prime is a nonword, the candidates are left in the open state for longer (although eventually they must close of their own accord).

Explaining why there is no form-priming for high-density targets is slightly more difficult. A reasonable assumption is that the match criterion might be set higher for a target word that closely resembles a large number of other words. Thus, for the same degree of overlap between the input stimulus and an entry, the probability of a candidate being declared as a CM is greater when it resembles fewer words.

**WHY IS IDENTITY PRIMING GREATER THAN FORM-PRIMING?**

If priming is due to entry-opening, why is there a greater savings when the target entry is marked as a VCM (identity priming) rather than a CM (form priming)? In an activation model, the answer is obvious: the amount of priming is a function of the amount of overlap between prime and target. Something similar could be suggested in the entry-opening model (a stimulus is more likely to open an entry if it matches the entry exactly), but this is not a deeply satisfying answer. A better answer would be that there are bigger savings in the case of an identity prime.

One way to approach this issue is to give up the idea that the lexical entry contains all the linguistic information about a word. In fact, we can think of the entry as containing no explicit information about the word at all. Rather, it just contains a set of keys (indexes) that permit the retrieval of further properties from other quite separate and independent data structures, which might be located in quite different areas of the brain. A complete opening of an entry would involve retrieving all these properties, but we assume this is undertaken only when the candidate is marked as a VCM. A CM only gets opened to the level of form so that it can be checked to see whether it is a reasonable candidate.

So, an identity prime will lead to a more complete opening of the target entry, and hence there is a greater savings. Obviously, this is not very different from the activation explanation. However, there are ways in which this theory can be distinguished from an activation account. For example, the entry-opening approach might give a different view of the additivity of priming effects. If the grounds for opening an entry as a candidate include both overall form overlap and/or morphological overlap (i.e., shared stems), then we would not expect additivity. An entry could be marked as a candidate
for any of several reasons, but being marked on two counts rather than one leads to no more savings.

As a concrete illustration of this idea, consider a morphological priming experiment that compares \textit{walks--WALK} with \textit{walk--WALKS}. Suppose we find superior priming in the first case compared with an orthographic control, but not in the second case. This result is anathema to a shared representation analysis, since symmetry of priming is a required outcome. But suppose that form-priming is strong when we remove a letter from the target (as in \textit{other--MOTHER}) but is weak or nonexistent when we add a letter to the target (e.g., \textit{mother--OTHER}). With the entry-opening model, this latter asymmetry can be used to explain the \textit{walks--WALK} asymmetry. The absence of a morphological effect for \textit{walk--WALKS} results from the fact that the overall form similarity is sufficient to produce a savings (as in \textit{other--MOTHER}), and it is therefore irrelevant whether the stems are similar or not. But if there is no form-priming when a letter is added (as in \textit{mother--OTHER}), then it is possible to observe shared-stem-priming for \textit{walks--WALK}. Constructing a similar account using an activation metaphor would be far more difficult. One would be led instead to seek more promising fields for research.

This is not the only example of nonlinearity in priming under investigation. Another example is the fact that there are circumstances in which identity-priming is no longer superior to form-priming. The first time this result was obtained was in an investigation of the effect of interpolating another word between the prime and the target (Forster, 1987). Since the masked priming effect decays very rapidly (Forster & Davis, 1984), one might have expected the weaker form-priming effect to virtually disappear. But form-priming seemed to be largely unaffected, whereas the identity effect was reduced sharply. Similar outcomes have subsequently been noted when prime and target are presented in different formats, e.g., mixed-case (e.g., cUsTaRd) vs normal-case (Forster & Guess, 1996) or same vs different fonts (Forster, 1994). In each case, identity-priming is reduced more than form-priming, with the result that there is no longer any significant difference between them. To explain these effects, we are currently developing a model of priming which exploits an idea suggested by Humphreys, Besner, and Quillian (1988). Their argument was that priming might depend on whether the prime and target are treated as a single perceptual object or as two distinct objects. Interpolating a word between the prime and target, or applying different formats to them, would force a dual-object interpretation. What this model seeks to show is that identity-priming depends crucially on a single-object interpretation. When this interpretation is blocked, the only effects we can observe are those of form-priming, which remain the same no matter which interpretation is adopted.

\footnote{This is not an entirely hypothetical situation. We have observed such effects in at least one experiment.}
Our conclusion from this research is that priming is far more complex than the simple activation metaphor assumes, and therefore caution is required when interpreting the results of priming experiments, masked or otherwise. At the moment, it is conceded that the entry-opening model earns poor marks for parsimony, and this will probably get worse as we struggle to make sense of findings such as these. But to win on grounds of parsimony alone with exploring the implications of these paradoxical results would be a Pyrrhic victory indeed.

REFERENCES


MICROGENESIS OF PRIMING


