LANGUAGE AND COGNITIVE PROCESSES
2005, 20 (1/2), 115–138

Psychology Press
Taylor & Francis Group

The locus and time course of long-term morphological priming

Jay G. Rueckl and Bruno Galantucci
University of Connecticut, Storrs, CT, and Haskins Laboratories, New Haven, CT, USA

Two experiments investigated the effects of long-term morphological priming in the fragment completion task. Completions for some of the fragments were presented visually during a preceding task, and others were presented auditorily. In addition, some of the target completions were morphologically related to words that were presented visually during the study task, while still others were unrelated to any of the study words. Fragments were most likely to be completed if either the completion or one of its morphological relatives was presented visually during the study task. Analyses of response latencies also indicated that the time course of morphological priming was similar to that of visual identity priming and that both morphological and visual identity priming had earlier influences than auditory identity priming. Overall, the results indicate that morphological priming includes a modality-specific component that reflects the operation of processes that occur relatively early in the time course of processing.

In a seminal paper, Murrell and Morton (1974) demonstrated that morphology plays an important role in visual word recognition. In the priming phase of their experiment, subjects studied a short list of words with the expectation that their memory for these words would later be tested. Shortly after the study phase, an identification task was administered. The accuracy with which words were identified during this task varied as a function of their relationships with words on the study list. Specifically, repeated words were identified more easily than unprimed

Correspondence should be addressed to Jay Rueckl, Department of Psychology, U-1020, University of Connecticut, Storrs, CT 06269. Email: jay.rueckl@uconn.edu.

This research was supported by Grant HD-01994 from the National Institute of Child Health and Development to Haskins Laboratories. We would like to thank Harald Baayen and an anonymous reviewer for their helpful comments

http://www.tandf.co.uk/journals/pp/01690965.html DOI: 10.1080/01690960444000188

words (i.e., words that were not related to any of the study words), as were words that had been preceded by a morphologically related prime (e.g., *cars* at study, *car* at test). Thus, both identity (repetition) priming and morphological priming facilitated identification. In contrast, no priming was observed for words that were preceded by morphologically unrelated primes that were similar in spelling and pronunciation (e.g., *card-car*).

Murrell and Morton's (1974) findings have been extended in numerous ways over the last three decades. The influence of morphological structure on visual word recognition has been demonstrated with a variety of experimental measures (e.g., lexical decision latencies, tachistoscopic identification accuracy, fixation duration, fragment completion rate), in a variety of languages (e.g., English, Chinese, Dutch, Finnish, and Italian), and using a variety of experimental manipulations (e.g., prime-target relationship, family size, stem frequency, etc.). (See Feldman, 1991, Henderson, 1985, and Marslen-Wilson et al., 1994, for reviews; and the papers in the Feldman, 1995, and Frost & Grainger, 2000, volumes for representative examples.) Given this wealth of evidence, it is now widely agreed that readers are influenced by the morphological structure of the words that they read. However, the psychological underpinnings of this influence remain a matter of debate.

One issue concerns the manner in which words are represented. One view, often termed the *decompositional* approach, holds that words are represented in terms of the morphological constituents (e.g., Taft & Forster, 1975). In contrast, *whole-word* (or *full-listing*) accounts (e.g., Feldman & Fowler, 1987; Lukatela, Gligorijevic, Kostic, & Turvey, 1980) hold that each morphologically complex word has its own representation, and that these representations are organised such that morphological relationships affect processing. A third class of models, *dual-process* accounts, assume that some morphologically complex words are represented in terms of their constituents and other are represented as whole words, with the choice of representation determined by factors such as the relative frequency of the word and its morphemes (Laudanna & Burani, 1995; Caramazza, Laudanna, & Romani, 1988) or the phonological and semantic transparency of the constituent morphemes (Baayen et al., 1997; Frauenfelder & Schreuder, 1991). Finally, a fourth class of models holds that words are represented by distributed patterns of activation, and that these representations are more-or-less componential in a way that reflects morphological structure (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000).

A second issue concerns the locus of morphological influences on the lexical processing system. One possibility is that morphological factors have a relatively early influence on word recognition. For example, some theories (e.g., Taft, 1994; Taft & Forster, 1975) hold that a word is decomposed into its morphemic constituents before lexical access occurs. For this sort of theory, morphological factors have their effects pre-lexically, and morphemes serve as the "access units" for word recognition. An alternative perspective is that the locus of morphological effects is the lexicon proper. On this view, morphological effects reflect the nature of the representations accessed in word identification, rather than the characteristics of the pre-lexical access units (Marslen-Wilson et al., 1994). A third theoretical perspective holds that morphological effects reflect neither the properties of the access units nor the organisation of lexical representations per se. Instead, on this view morphological effects reveal the operation of post-access processes that are sensitive to morphological structure (Giraudo & Grainger, 2001; Henderson et al., 1984; Manelis & Tharp, 1977).

Two points concerning the locus of morphological effects are worth noting. First, the theoretical alternatives are not necessarily mutually exclusive. It is perfectly conceivable that morphology influences more than one stage of lexical processing and that different morphological effects reflect the operation of different stages of processing (see Marslen-Wilson et al., 1994, for further discussion of this point). Second, it seems fair to say that questions about the locus of morphological effects have been somewhat neglected in the literature on morphology and word recognition. For example, in reviewing relevant papers in preparation for writing this article, we found that whereas virtually every theoretical proposal very carefully articulated a position about how morphological structure is represented, in a surprising number of cases it was difficult to ascertain what was being proposed about the processing locus of morphological effects. The same conclusion was reached by Marslen-Wilson et al. (1994, p. 4), who wrote that "psycholinguistic research into morphological complex words has often failed to maintain this distinction [between access units and lexical entries], making it hard to sort out whether claims and evidence for full-listing or morpheme-based accounts apply to the access representation, the lexical entry or both."

The purpose of the experiments reported in this paper was to investigate the processing locus of long-term morphological priming. Given that different morphological effects may have different processing loci, it is worth emphasising that we are specifically concerned with long-term priming, in which the presentation of a number of items (typically at least ten and often many more) intervenes between the presentation of the prime and target, and thus seconds, minutes, or even days pass between these two events. Morphological effects are also observed in "short-term" priming tasks, in which the target is usually presented immediately after the prime (e.g., at a lag of 0–1000 ms). Although morphological effects are evident in both paradigms, there is good reason to suppose that different mechanisms underlie short- and long-term priming. For example, while semantic relatedness usually results in substantial short-term priming, long-term priming based on semantic relatedness alone has rarely been reported (see Rueckl, 2002, for further discussion).

The approach we took to investigate the locus of long-term morphological effects was inspired by a body of research concerning the processes underlying a related phenomenon: long-term identity priming. In the next section we review this body of research. We then report two experiments suggesting a relatively early locus for long-term morphological priming.

MODALITY-SPECIFIC AND MODALITY-INDEPENDENT CONTRIBUTIONS TO IDENTITY PRIMING

One issue that has been carefully explored in studies of long-term identity priming is whether or not priming reflects the operation of processes that act at an abstract, modality-independent level. Early models of identity priming, most notably Morton's logogen model (Morton, 1969), answered in the affirmative. In Morton's model, words are represented by processing units called logogens, and word recognition occurs when enough perceptual evidence suggesting the presence of a particular word accumulates, causing that word's logogen to cross its threshold. One of the consequences of crossing threshold is that the threshold is then lowered, so that less evidence is needed for the logogen to cross the threshold again. Identity priming effects are a behavioral manifestation of this change in threshold.

In the original version of the logogen model (Morton, 1969), it was assumed that the same logogen was involved in reading a printed word, hearing a spoken word, or selecting a word when speaking. Because logogens are assumed to be modality-independent, Morton's model predicts that identity priming should transfer broadly across modalities and tasks. However, this turns out not to be the case. For example, Winnick and Daniel (1970) found that the recognition of a printed word was not primed as a result of naming that word aloud in response to either a picture or a definition. Morton (1979) replicated Winnick and Daniel's (1970) results and also found that hearing a word did not facilitate the subsequent recognition of its written form.

Based on evidence of this sort, Morton (1979) hypothesised that different cognitive processes draw on different sets of logogens. For example, to account for the Winnick and Daniel (1970) and Morton (1979) findings, the revised logogen model included distinct banks of logogens for visual word recognition, spoken word recognition, and speech production. Hence, hearing or producing a word doesn't facilitate the subsequent recognition of its visual form because the logogens activated during the former processes are not the same logogens responsible for visual word recognition. The revised logogen model thus places the locus of identity priming effects at a modality-specific level of representation. Moreover, based on Murrell and Morton's (1974) observation that the recognition of a word can be primed by prior exposure to a morphological relative of that word, logogens were thought to represent morphemes, rather than whole words. Thus, according to the logogen model identity priming and morphological priming have a common basis: changes in the thresholds of modality-specific access units.

Although the revised logogen model accounted for an impressive array of the empirical findings of its day, subsequent research has shown that it is wrong in several important ways. One problem is that it is based on the conclusion (drawn from the Winnick and Daniel, 1970, and Morton, 1979, results) that hearing or generating a word will have no effect on the subsequent identification of its written form. However, the results of a large number of more recent studies contradict this assumption. It is now generally accepted that changes in modality between the prime and the target reduce, but do not eliminate, repetition priming (see Kirsner, Dunn, & Standen, 1989, and Roediger & McDermott, 1993, for reviews). This pattern of results suggests that both modality-specific and modality-independent processes contribute to priming. The contribution of modality-specific processes gives rise to the advantage of same-modality priming; cross-modal priming reflects the contribution of more abstract, amodal processes involved in seeing, hearing, and perhaps producing a word (Kirsner et al., 1989; Weldon, 1993). (Substantial evidence points to both phonological and semantic loci for the modality-independent components of priming; see Rueckl and Mathew, 1999, and Weldon, 1991, 1993, for further discussion.)

In addition to failing to account for the modality-independent source of priming effects, a second problem for the revised logogen model is that it does not fully capture the characteristics of modality-specific priming effects. For example, in the logogen model priming should only occur when familiar words (or morphemes) are repeated. However, a variety of studies have demonstrated that priming facilitates the processing of unfamiliar pseudowords and nonwords (see Rueckl, 2002, and Tenpenny, 1995, for reviews), and under certain conditions priming transfers to orthographically similar items, suggesting that priming has a pre-lexical basis (see Rueckl, 2002, for a review). Similarly, whereas the logogen model assumes that modality-specific access units are perceptually abstract (across variations in font, size, and other perceptual characteristics), differences in the perceptual characteristics of the prime and target sometimes result in a reduction in the magnitude of priming (see Rueckl, 2002, and Tenpenny, 1995, for reviews). While their theoretical implications are a matter of some debate (cf. Bowers, 1996; Brown & Carr, 1993; Jacoby, 1983; Marsolek, Kosslyn, & Squire, 1992; Roediger, 1990; Rueckl, 2002), these results imply that the modality-specific component of priming cannot be ascribed solely to changes in modality-specific lexical/morphemic access units. Indeed, these results suggest that the modality-specific component may itself reflect the contribution of several distinct processes.

THE LOCUS AND TIME COURSE OF MORPHOLOGICAL PRIMING

Given the evidence that has emerged from the investigation of identity priming, several hypotheses about the locus of morphological priming can be formulated. On the one hand, theories that hold that morphological effects in reading arise from the organisation of the central lexicon suggest that morphological priming should be aligned with the modality-independent component of identity priming. Alternatively, theories that hold that words are decomposed into their morphological components prior to lexical access suggest a modality-specific basis for morphological priming. To be clear, these hypotheses about the locus of morphological priming are not mutually exclusive. As noted above, the influence of morphological factors at one level of processing does not preclude the possibility that morphology matters at other levels as well. Thus, just as long-term identity priming includes several components, so too might long-term morphological priming. Consequently, the goal of the present experiments was not to identify "the" locus of morphological priming. Instead, these experiments were designed to evaluate the hypothesis that morphological priming is due (at least in part) to processes involving modality-specific representations.

A second (and related) goal was to gain evidence about the time-course of morphological priming. The rationale for this aspect of our study was based on Weldon's (1993) observation that the contribution of modality-specific processes to identity priming occurs earlier than does the contribution of modality-independent processes. Because Weldon's study played an especially critical role in the design and interpretation of our experiments, we describe it in some detail here.

Weldon (1993) examined priming in a visual word-fragment completion task, in which participants are asked to complete a fragment such as ___l___p___a___t with the first word that comes to mind. (For this example, "elephant" is the only legal completion.) In addition to an unprimed baseline condition, there were three other priming conditions: During a seemingly unrelated task that preceded the fragment completion task, participants either saw a target word ("elephant"), heard it, or saw a corresponding picture. Whereas modality-independent priming might occur in all three of these conditions, only visual identity primes would be expected to give rise to modality-specific priming.

Weldon (1993) considered the test fragment to be a retrieval cue that sometimes elicits representations stored during the processing of a prime. She reasoned that, if modality-specific representations are accessed before modality-independent representations, these two components of identity priming should have different time courses. In Experiment 1, information about the time course of priming was obtained by varying how long each test fragment remained visible. With relatively brief fragment durations (500 ms and 1 s), only visual word primes increased the completion rate. However, at longer durations (5 and 12 s) spoken primes (and to a lesser extent, picture primes) also improved performance, although not as strongly as visual identity primes did. This pattern of results suggests that the modality-specific component has a faster time course, as would be expected if seeing a word primes relatively early, modality-specific processes while either hearing or seeing a word primes relatively late, modality-independent operations.

In a second experiment, Weldon (1993) looked at the time course in a different way: by measuring response latencies. She found that, when differences in the completion rate were taken into account, visually primed fragments were solved at a faster rate than either auditorily or pictorially primed fragments, again suggesting the modality-specific and modality-independent components of priming have different time courses.

In the experiments presented below, we adapted Weldon's (1993) methodology to examine the time course of morphological priming. Participants performed two tasks—a pleasantness judgement task (the study task), followed by a fragment completion task (the test task). As in Weldon's experiments, some of the target completions were presented visually during the study task, others were presented auditorily, and some were unrelated to any of the words presented during the study task. Unlike Weldon's experiments, however, there were no picture primes. Instead, some of the study words were morphological relatives of the target completions (e.g., *arrangement-arrange*). The morphological primes included both inflections and derivations and were always presented visually. As was the case in Weldon's (1993) study, the time course of priming was examined in two ways. In Experiment 1, the fragments were presented for varying durations. In Experiment 2, the fragments were presented for a fixed duration and response latencies were recorded.

In summary, the present experiments were designed to gain information about the locus and time course of morphological priming by comparing visual morphological priming to both visual and auditory identity priming. While the visual identity condition provides an estimate of the combined effects of modality-specific and modality-independent priming under these experimental circumstances, the auditory identity condition provides a benchmark for the maximal contribution of modality-independent processes[1]. Thus, if morphological priming is purely a consequence of processes with an amodal central lexicon, within-modality morphological priming and cross-modal identity priming should be similar in both magnitude and time course. In contrast, if morphological priming includes a modality-specific component, morphological and auditory identity priming should differ in both magnitude and time course, with morphological priming more closely resembling visual identity priming. (In the latter case, if morphological and visual identity priming differ in either magnitude or time course, these differences could reflect either modality-specific [visual or orthographic] or modality-independent [semantic, phonological, or lexical] factors. Converging evidence would be necessary to disentangle these possibilities.)

EXPERIMENT 1

Method

Participants. Seventy-two undergraduates from the University of Connecticut participated for course credit. All the participants were native speakers of English with normal or corrected vision.

Design. A 4 × 3 mixed design was used with priming condition manipulated within subjects and fragment exposure times manipulated between subjects. The four priming conditions were visual identity, auditory identity, visual morphological, and unrepeated (baseline). The three exposure times were 1, 5 and 12 s. The assignment of target words to study condition was completely counterbalanced so that, across participants, each item appeared in each priming condition an equal number of times.

Materials. The target items were the solutions of 60 word fragments. The targets were low- to moderate-frequency words (mean 86, range 0–465; Kucera & Francis, 1967) and ranged in length from 5 to 9 letters. The 60 test fragments were selected from a larger set of fragments whose level

[1] Note that we could have used cross-modal morphological priming, rather than cross-modal identity priming, as our index of the modality-independent contribution to priming. Also note that identity priming is a special case of morphological priming—one in which only the target morpheme is presented during the priming event. We chose to use cross-modal identity priming to maximise the magnitude of cross-modal priming, and thus provide a conservative test of the hypothesis that (visual-visual) morphological priming includes a modality-specific component.

of difficulty, in absence of priming, was assessed in a pilot experiment. The average percentage of correct solutions in a sample of ten subjects for the set of fragments selected was 25% (range: 10–40%). Fragments were formed by removing 25–50% of a target word's letters, with the constraint that the only legal completion for a given fragment was its target word.

In the morphological priming condition, the relationships between the primes and their targets were rather heterogeneous, including verbal inflections (e.g., *consumed/consume*), nominal inflections (*hammers/hammer*), and various types of derivations (e.g., *believer/believe*; *systematic/system*; *arrangement/arrange*). The prime-target pairs were selected so that the morphological relationships were orthographically, phonologically, and semantically transparent.

The assignment of items to priming conditions was counterbalanced by partitioning the 60 target words into four sublists of 15 words each and rotating these sublists through the priming conditions. Across subjects, each word appeared in each priming condition an equal number of times.

Each participant was presented with the same list of fragments to complete. This list included the 60 critical fragments, along with 30 fillers. None of the completions for the filler fragments were presented during the study task. Thus, of the 90 fragments presented during the completion task, 45 were related to words presented during the study task, and 45 (the 15 items in the unprimed condition plus the 30 fillers) were not. The fillers were included to reduce the likelihood that participants would attempt to complete the fragments by consciously trying to recall words from the study task.

For the auditory condition a male native speaker of American English was recorded producing each of the target words. These recordings were digitised using the Sound Edit 16 software for the Macintosh. The intelligibility of these recordings was checked through the judgements of another native speaker of American English, who reported that each recording was clear and understandable. The visually presented stimuli in both tasks appeared in the centre of a computer screen in 18-point extended Courier font. (Courier is a fixed width font, and thus letter spacing provided no cues about the identity of the absent letters.)

Procedure. Participants were tested individually or in pairs. They were told that they would perform several tasks concerning various aspects of their knowledge of words. The experiment included three distinct phases. During the first phase, the participants judged the pleasantness of each of a list of words on a scale from 1 to 5. The list included six buffer items (the first three and last three words in the series) and 45 target words (15 each in the visual, morphological, and auditory conditions). The words from the different priming conditions were intermixed and presented in a different random order for each subject. The words in the auditory condition were presented over headphones; the words in the visual and morphological conditions appeared in the centre of a computer screen

Immediately after the study phase, the participants completed an irrelevant filler task in which they were given three minutes to write down the names of as many magazines as they could remember. The filler task was then followed by the test phase, during which the participants performed a fragment completion task. The fragments of the 60 critical items and 30 filler items were intermixed and presented in a random order. Each fragment was visible for a maximum of 1, 5 or 12 s, depending on the duration condition to which the participant was assigned. In the 1-s and 5-s conditions the presentation of the fragment was followed by an additional 5-s response interval. Upon discovering the completion for a fragment, the participant clicked the computer mouse to terminate the trial, and then typed the solution when prompted. If no response was made before the end of the trial, the participant was encouraged (but not required) to guess.

The experiment was controlled by a HyperCard program running on Macintosh computers. After the test phase participants were briefly interviewed about their impressions on the tasks. They were asked if they noticed that some of the words repeated themselves in different tasks of the experiment and, if they answered yes, they were asked if they used memories from the study-phase to help themselves in the test-phase. Finally, they were debriefed and thanked.

Results

A response was scored as a target completion only if it exactly matched the target word. Thus, apparent misspellings and other responses were considered misses. The target completion rates for the various study conditions are presented in Figure 1. Inspection of the figure reveals that the results are broadly consistent with those of Weldon (1993): Completion rates increased with longer fragment exposure durations and as a result of exposure to a target word during the study task. This description of the data is consistent with the results of an analysis of variance (ANOVA) which revealed significant main effects of study condition, by participants, $F_1(3, 207) = 20.93, p < .0001$, and by items, $F_2\ (3, 177) = 24.21\ p < .0001$, and exposure duration, $F_1\ (2, 69) = 4.75, p < .05$, $F_2\ (2, 59) = 5.31\ p < .01$. The interaction of these factors was not significant, $F_1 < 1$, $F_2 < 1$.

A set of planned comparisons was performed to examine the differences among the study conditions. These comparisons revealed significant priming effects—in the form of elevated target completion rates relative to the baseline condition—in the visual, $F_1(1, 71) = 56.18$, p < . 0001, $F_2(1, 59) = 64.97, p < .0001$, morphological, $F_1(1, 71) = 33.52, p < .0001$, $F_2(1, 59) = 38.77, p < .0001$, and auditory, $F_1(1, 71) = 12.89, p < .001$, $F_2(1, 59)$

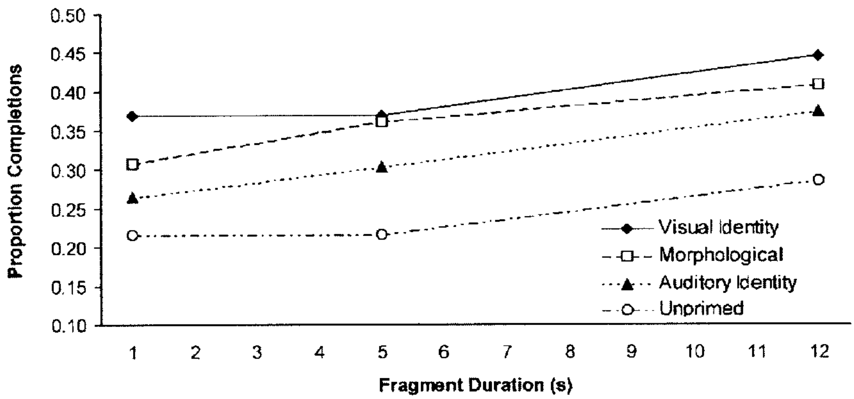

Figure 1. Target completion rates as a function of priming condition in Experiment 1.

$= 14.91$, $p < .001$, study conditions. Moreover, there were significantly more target completions in the visual priming condition than in the auditory condition, $F_1(1, 71) = 15.25$, $p < .0001$, $F_2(1, 59) = 17.63$, $p < .0001$, and similarly, more fragment completions in the morphological priming condition than in the auditory condition, $F_1(1, 71) = 4.84$, $p < .05$; $F_2(1, 59) = 5.6$, $p < .05$. Thus, there was a significant effect of cross-modal priming, but more priming occurred when both the study and test items were presented visually. Finally, although the target completion rate was somewhat higher in the visual condition than in the morphological condition, this difference was only marginally significant, $F_1(1, 71) = 2.91$, $p = .09$; $F_2(1, 59) = 3.36$, $p = .07$, and seemed to vary with presentation duration. (Post-hoc analyses revealed that the difference between the visual and morphological conditions was only significant in the 1-s duration condition.)

As a methodological aside, the short interviews of the participants at the end of the experiment revealed that most of the participants were aware of the fact that some words were present in two tasks. However, the impression most commonly reported by the participants about the effects of this repetition was that, during the process of looking for a solution for the target, the solutions "popped out" all of a sudden when they were words already encountered in the previous list. None of the participants claimed to have strategically used this knowledge about the repetition of some words in the two tasks. Consistent with the self-reports, the data from the baseline condition also suggest that participants did not adopt an explicit memory strategy. Such a strategy should be detrimental in the case of unprimed words, for which attempts to recall items from the study task would fail to generate a correct response. In fact, however, the completion rate in the unprimed rate was quite similar to what was found in the pilot experiment used to select the materials (24% in the experiment, 25% in the pilot experiment).

Discussion

Several aspects of the results are particularly noteworthy. First, a target word was more likely to be generated as a fragment completion if it was primed by a visually presented morphological relative than if it was primed by itself in the auditory identity condition. Because identity priming is, in a sense, the strongest possible case of morphological priming (one in which only the root morpheme is presented during the priming event), the auditory identity condition provides an upper limit for the contribution of the modality-independent component of priming under these conditions. The fact that priming was greater in the morphological condition than in the auditory condition thus provides strong evidence that morphological priming, like identity priming, includes a modality-specific component.

The evidence concerning the time course of morphological priming is less clear. The pattern of results suggests that morphological priming has an earlier influence on processing than does cross-modal identity priming, and that the effect of morphological priming is delayed slightly in comparison to visual identity priming. However, given the lack of a significant interaction of duration and priming condition and the differences among the priming conditions at the longest duration presentation, one could argue that the differences at the shortest duration are related to the magnitude of priming, rather than its time course. Because the results of the second experiment yield more definitive evidence about this point, we will not belabour it here.

EXPERIMENT 2

Like Experiment 1, Experiment 2 investigated the effects of visual identity, morphological, and auditory identity priming on visual fragment completion rates. In the second experiment fragment presentation duration was not manipulated. Each fragment was presented for a maximum of 16 s, and response latencies were measured along with target completion rates.

Method

Participants. Thirty-two undergraduates from the University of Connecticut participated for course credit. All the participants were native speakers of English with normal or corrected vision.

Design and procedure. The design and procedure of Experiment 2 were identical to those of Experiment 1, with three exceptions. First, fragment presentation duration was not manipulated. Each fragment was presented for 16 s or until the participant clicked the mouse to indicate that he or she had found a completion. Second, response latencies (defined as the length of the interval between the onset of the fragment and the mouse click that indicated that a solution had been found) were recorded. Third, only responses that were initiated before the end of the 16 s presentation duration were treated as possible target completions. (As in the first experiment, if the participant had not clicked the mouse by the end of the response interval, he or she was prompted to guess. However, because the response latencies of these late guesses are not well defined, they were treated as misses for all of the analyses. Late correct responses occurred on only 41 of 1920 total trials (2.13%), and the same pattern of effects were obtained whether or not they were included in the completion rate analyses.)

Results

Target completion rates. As in Experiment 1, responses were scored as target completions only if they exactly matched a target word, and apparent misspellings were treated as misses. Table 1 presents the target completion rates in Experiment 2 as a function of study condition. The effect of study condition was significant by both subjects, $F_1(3, 93) = 5.59$, $p < .001$, and items, $F_2(3, 177) = 5.94$, $p < .001$. A set of planned comparisons was performed to examine the differences among the priming conditions. Relative to the baseline condition, significant priming effects were observed in both the visual identity, $F_1(1, 31) = 13.06, p < .001$; $F_2(1, 59) = 14.01, p < .001$, and morphological, $F_1(1, 31) = 9.08, p < .01$; $F_2(1, 59) = 5.94, p < .001$, study conditions. In addition, more fragments were completed in the visual identity condition than in the auditory identity condition, $F_1(1, 31) = 3.95$, $p = .056$; $F_2(1, 59) = 5.20$, $p < .05$. Finally, although the effects were numerically comparable to those of Experiment 1, the differences between the morphological and auditory conditions and between the auditory and baseline conditions were not statistically

TABLE 1
Fragment completion rates in Experiment 2

Priming condition	*Completion rate*
Visual identity	.41
Morphological	.39
Auditory identity	.34
Unprimed	.29

TABLE 2
Response times in Experiment 2

Priming condition	*Mean*	*Median*	*SD*	*Skew*	*Kurtosis*
Visual identity	4510	3100	3593	1.39	1.13
Morphological	4418	3183	3432	1.61	1.94
Auditory identity	5392	4150	3618	0.86	−0.24
Unrepeated baseline	5763	4367	4007	0.96	−0.15

significant. Presumably the lack of statistical significance for these comparisons is due to the smaller sample size in the present experiment.

Response times. Table 2 displays the mean response times (along with other summary statistics) for trials on which the target completions were generated. As is typically done with response time data, ANOVAs were conducted to analyse the results. In contrast to the results of the analyses of completion rates, the main effect of study condition was only marginally significant, $F_1(3, 93) = 2.31$, $p = .082$; $F_2(3, 177) = 2.6$ $p = .10$. Consequently, no comparisons were performed to examine the differences among the priming conditions.

While it is certainly possible that a manipulation might have a stronger influence on completion rates than on response times, several considerations suggest that for this kind of experiment an ANOVA obscures, rather than reveals, the pattern in the data. First, the numerical differences among the conditions were often large and patterned as would be expected based on the completion rates. However, the variability in response times was substantial in comparison to typical results from other response time paradigms (e.g., lexical decision, speeded naming). The relatively large standard deviations observed in the present experiment do not reflect unusually small numbers of subjects or items, but instead are intrinsic to this form of the fragment completion task: Completions are often found within 1 or 2 seconds, but are also found after 10 or 15 seconds of search. A related concern is that, in addition to the high variability, the RT distributions in each of the four study conditions are positively skewed, and the distributions for the visual and morphological conditions are also substantially kurtotic (see Table 2). Thus, not only are the RT distributions non-normal (thus violating one of the assumptions of ANOVA),[2] but their shapes differ as a function of study condition (see Figure 2). Finally, in the ANOVA trials on which the target completion was not generated before the deadline (65% of the total) were excluded. Thus, the ANOVA failed

[2] Kolmogorov–Smirnov tests for normality confirmed that the four distributions are all non-normal ($p < .001$ for all four distributions).

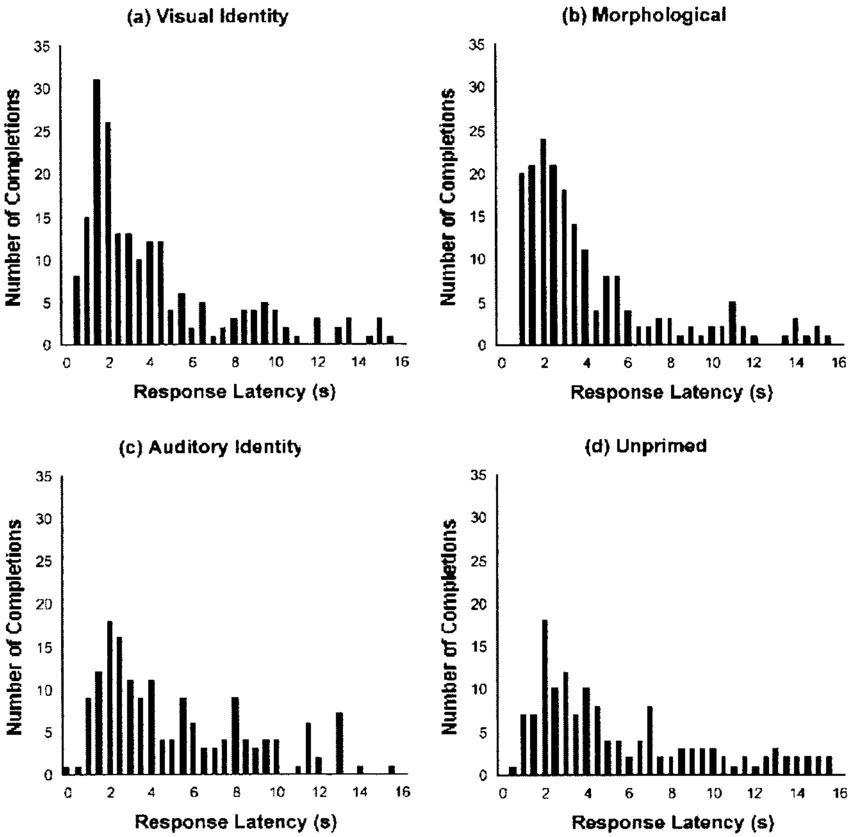

Figure 2. The distribution of target completion latencies in Experiment 2 as a function of priming condition.

to make use of the information that these trials provide. Moreover, the number of "missing" trials varied across study conditions: Trials were excluded most often in the unprimed condition and least often in the visual identity condition. Systematic differences in exclusion rates could easily give rise to potentially misleading results. (For example, if priming decreases the time needed to complete a fragment, some of the trials that would have been solved after the deadline in the baseline condition might have been solved before the deadline in a primed condition. Such trials would be excluded from the computation of the baseline RT, but would increase the mean RT in the primed condition, resulting in an artificially slow average RT in the primed condition relative to the unprimed condition.)

Cumulative proportion-of-asymptote. Together, the preceding considerations imply that analyses of the present data based on average response times are at best weak, and at worst, misleading. Clearly, a different type of analysis that addresses these considerations is desirable. One possibility was suggested by Weldon (1993). To analyse the time course of processing in her fragment completion experiment, Weldon plotted the cumulative frequency of target completions as a function of response latency. To address the fact that the cumulative frequency functions approached different asymptotes in the different study conditions, the cumulative frequency functions were transformed into cumulative proportion-of-asymptote functions. The results allowed Weldon to conclude that within-modality priming is not only larger in magnitude than cross-modal priming, but also that within-modality priming occurs earlier in the time course of fragment completion.

We applied the cumulative proportion-of-asymptote analysis to the results of Experiment 2. Response times were grouped into 1 s bins, and the cumulative frequency of target completions for each bin was plotted as a proportion of the total number of completions at the end of the 16-s response period (see Figure 3). Not surprisingly, the effect of response period was significant, $F(15, 465) = 418.13$, $p < .0001$.[3] More importantly, although the effect of priming condition was not significant ($F < 1$), there was a significant interaction of priming condition and response period, $F(45, 1395) = 2.023$, $p < .0001$. Interaction contrasts confirmed what the pattern depicted in Figure 3 suggests: The time course of priming of visual identity and morphological priming differed from that of auditory identity priming; visual/auditory × response interval: $F(15, 465) = 2.283$, $p < .005$; morphological/auditory × response interval: $F(15, 465) = 4.086$, $p < .0001$. In contrast, neither the difference between morphological and visual identity priming nor the interaction with response period was significant. Similarly, there were no significant effects involving the contrast between the auditory priming and unprimed baseline conditions.

Survival analysis. Compared to ANOVA, the cumulative proportion-of-asymptote analysis is more revealing about the time course of processing. Nonetheless, it is less than ideal in several respects. One concern is that, given that the choice of a deadline is arbitrary, scaling the cumulative functions relative to a deadline-dependent measure is somewhat arbitrary as well. That is, to the degree to which different deadlines yield different estimates of asymptotic performance, the apparent relationships among

[3] Because there were only eight observations per item per condition, analyses with items treated as random variables were not conducted.

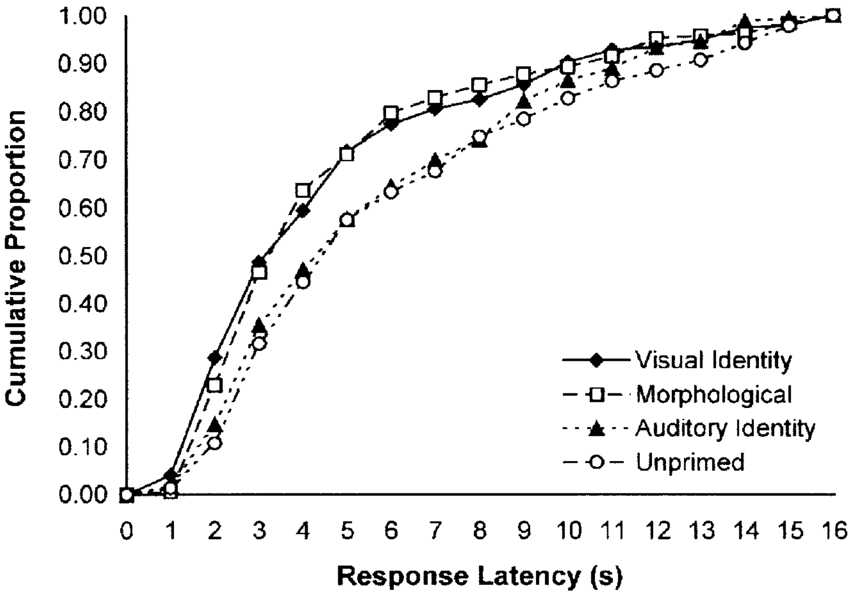

Figure 3. Cumulative-proportion-of-asymptote as a function of priming condition in Experiment 2.

the cumulative proportion-of-asymptote functions for the different study conditions will also tend to vary. A second concern is that the choice of bin size is also somewhat arbitrary, and while using too few bins could obscure real differences in the time course of priming, using too many bins could inappropriately magnify neglible differences among the conditions. A third and particularly important concern is that, because it is insensitive (by design) to differences in the asymptotic completion rate, the cumulative proportion-of-asymptote analysis fails to make use of the information provided by trials on which the target completion was not found. An approach that addresses these shortcomings is *survival analysis*.

Survival analysis, first developed as a tool for analysing data in actuarial mathematics, has become a common instrument of statistical investigation whenever the time course of a series of events as well as the distribution of lost observations (censored data) are of central interest. (For a general introduction to survival analysis see Lee, 1992 or Klein & Moeschberger, 1997.) Consider, for example, an experiment meant to compare the effectiveness of two cancer treatments. The critical observations in such an experiment are the "survival periods", the intervals between treatment and death for those patients that died during an observation period. However, some of the patients may survive until the end of the observation period, and some may die for reasons other than cancer (e.g., car accidents). The fact that a patient was alive at the end of the observation period or until an unrelated death provides information concerning the effectiveness of the treatment, but in neither case is it appropriate to consider the end of the observation to be the end of the survival period. The mathematical underpinnings of survival analysis allow it to take information from these censored cases into account.

In the case of the present experiment, the critical events (comparable to cancer-related deaths in the example) were responses indicating that a target completion had been found. Thus, only trials on which a target response was reported (as indicated by a mouse click) before the end of the 16-s response interval yielded an observable survival period. This occurred on 36% of the trials. The remaining trials were classified into two types. Trials on which a wrong or null answer was given before the end of the response interval (33% of the trials) were "left-censored". These trials are the analogue of car-accident victims in the cancer example. Trials on which the participant did not respond before the end of the response interval were "right-censored". These trials (31% of the total) are analogous to the patients who are still alive at the end of the observation period in the cancer example.

The nonparametric Kaplan–Meier survival function for each priming condition is presented in Figure 4. A Gehan's Wilcoxon test for the equality of the survival distributions revealed that the type of priming had a highly significant effect, $\chi^2(3) = 32.45$, $p < .0001$. A set of planned

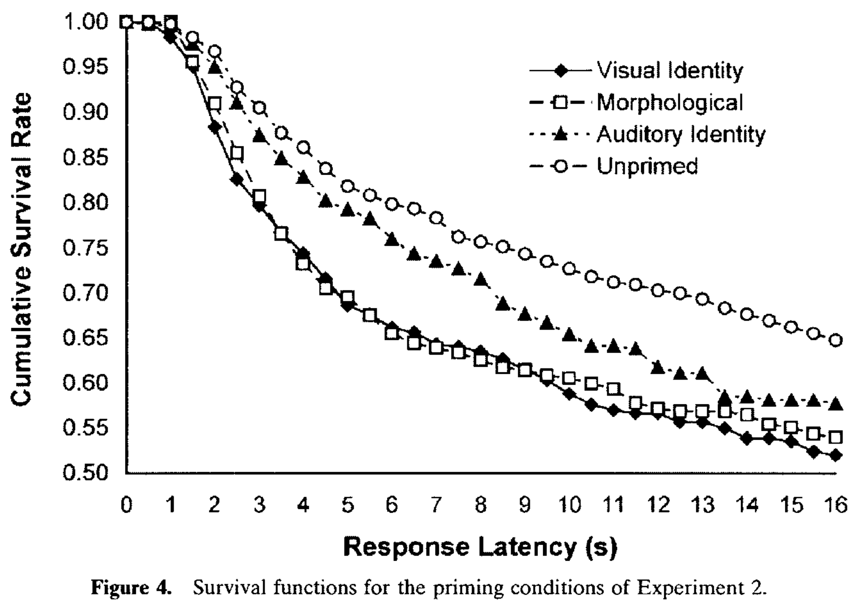

Figure 4. Survival functions for the priming conditions of Experiment 2.

pairwise Wilcoxon tests was performed to examine the differences among the priming conditions. All the priming conditions led to significantly lower survival rates than the baseline, $\chi^2(1) = 24.17$, $p < .0001$ for the visual identity condition; $\chi^2(1) = 20.52$, $p < .0001$ for morphological priming, and $\chi^2(1) = 4.23$, $p < .05$ for the auditory identity condition. Moreover, the survival rates for both the visual identity and morphological conditions differed significantly from that of the auditory identity condition, $\chi^2(1) = 9.39$, $p < .01$ for visual identity priming, $\chi^2(1) = 7.31$, $p < .01$, for morphological priming. The survival rates for the visual identity and morphological priming conditions were not significantly different, $\chi^2(1) < 1$.

Discussion

The target completion rates in Experiment 2 closely resembled those of the first experiment, providing additional evidence of a modality-specific contribution to morphological priming. Evidence concerning the time course of priming also supports this conclusion. The results indicate that morphological priming and visual identity priming have similar time courses, and that both forms of priming exert an earlier influence on fragment completion than does cross-modal priming.

As did Weldon (1993), we assume that fragment completion, like word recognition more generally, involves a variety of modality-specific (e.g., visual, orthographic) and modality-independent (e.g., lexical, semantic, phonological) processes. We further assume that these processes operate in a cascaded fashion, with the presentation of a word fragment initiating modality-specific processes, and these processes in turn driving other, modality-independent processes. Hearing a word leaves a lasting influence on one or more of the modality-independent processes, whereas seeing a word influences both modality-specific and modality-independent processes. The relatively early effect of visual identity and morphological priming (i.e., the greater likelihood of generating the target completion in the first few seconds after the fragment is presented) is a manifestation of this difference—it is in these conditions that priming has the largest impact on early-occurring, modality-specific processes.

GENERAL DISCUSSION

One goal of the present study was to determine whether long-term morphological priming involves a modality-specific level of representation, or if instead the only level at which morphological priming occurs is that of central, modality-independent representations. The results clearly demonstrate that morphological priming has a modality-specific component. In both experiments, target completions were more likely to be generated when they were preceded by visually presented morphological primes than by auditorily presented identity primes. Because the auditory identity condition provides an upper limit for the contribution of the modality-independent component of priming, the difference between the morphological and auditory primes can be taken as strong evidence that morphological priming has a modality-specific component.

Evidence concerning the time course of priming also supports this conclusion. The strongest time-course evidence comes from the results of Experiment 2, where both the survival analysis and the cumulative-proportion-of-asymptote analysis revealed that morphological priming had an earlier effect on fragment completion than did auditory identity priming. This difference between morphological and cross-modal priming, as well as the fact that the time course of morphological priming closely resembled that of visual identity priming, is what would be expected if morphological priming influences modality-specific processes that operate relatively early in processing.

This interpretation of the results assumes that priming in the morphological condition was truly a consequence of the fact that the primes and targets in that condition were morphologically related. However, given that morphologically related words are usually similar in form and in meaning, it is fair to ask whether our putative "morphological" priming effects were truly morphological in character. Could it be the case, for example, that the modality-specific component of priming in the morphological condition was actually a consequence of the orthographic similarity between the primes and targets?

While this possibility cannot be ruled out on the basis of the present results alone, the available evidence suggests that it is highly unlikely that it is the correct interpretation of our results. Although effects of orthographic similarity are often found in short-term priming paradigms, they are far less commonly observed in long-term priming studies. In a review of such studies, Rueckl (2002) concluded that priming based on orthographic similarity is unlikely to be observed unless there are (a) multiple repetitions of an orthographically related prime, (b) multiple related primes, (c) relatively unfamiliar targets (e.g., pseudowords), or (d) relatively unskilled readers (e.g., 3rd graders). When these conditions are not met (as is the case for the present experiments), priming is typically not observed for orthographically similar primes and targets unless they are morphologically related. (See, for example, Drews & Zwisterlood, 1995; Feldman, 2000; Murrell & Morton, 1974; Napps & Fowler, 1987; Ratcliff & McKoon, 1996; Rueckl & Mathew, 1999; Stolz & Feldman, 1995.) For present purposes, perhaps the most telling of these findings was reported by Rueckl, Mikolinski, Raveh, Miner, & Mars (1997), who also studied the effects of long-term morphological priming on fragment completion. In

Experiment 2 of that study morphologically related and unrelated primes were matched in terms of their orthographic similarity to their corresponding targets (e.g., *blanked-blank* vs. *blanket-blank*). While there was substantial priming in the morphologically related condition (comparable to the effects observed in the present study), there was no evidence of priming in the orthographic control condition.

Taken together, then, present and past results support the conclusion that morphological priming influences modality-specific processes. This conclusion is consistent with models of word recognition that hold that morphological structure is represented at a relatively early stage of processing (e.g., by modality-specific access units, Taft, 1994, or in the organisation of the distributed representations that mediate the mapping from visual input to meaning; Rueckl et al., 1997). Other findings provide converging evidence for an early influence of morphology. For example, Rueckl et al. (1997) found that morphological priming effects varied as a function of orthographic similarity. Similar prime-target pairs (*made-make, bit-bite*) produced more priming than dissimilar pairs (*took-take, bought-buy*). This interaction indicates a relatively early locus for morphological priming—early enough for orthography to be a relevant factor. An early influence of morphology is suggested by phenomena other than morphological priming, as well. For example, Prinzmetal et al. (1986) demonstrated a morphological influence on perceptual grouping—a process typically considered to be "too early" to be of direct interest to models of lexical processing.

As noted in the Introduction, evidence for a modality-specific locus for morphological priming does not imply that more central processes do not also contribute to morphological priming effects. However, attempts to isolate such a contribution—for example, by varying the semantic relatedness of morphologically related prime-target pairs—have generally proven unsuccessful (e.g., Bentin & Feldman, 1990; Raveh & Rueckl, 2000). Nevertheless, given the relative insensitivity of most priming measures to manipulations of this sort (see Weldon, 1991, 1993, for discussion), these null effects do not provide a compelling basis for concluding that morphological structure is only relevant at the level of, say, modality-specific access units. Indeed, given the nature of the evidence concerning morphological influences in other word recognition paradigms (e.g., Frost, Forster, & Deutsch, 1997; Gonnerman, Devlin, Andeersen, & Seidenberg, 1995; Marslen-Wilson et al., 1994), and the importance of morphology for various language comprehension and production processes more generally, it seems implausible to suppose that morphological structure is only represented at the level of the modality-specific representations involved in visual word recognition. In other words, our results are not inconsistent with claims that the "mental lexicon"—an amodal, abstract level of representation—is morphologically structured. However, our results do imply that such accounts are incomplete unless they allow for morphological influences at other levels of representation as well.

To conclude, the present results are generally consistent with accounts that hold that morphological structure influences relatively early ("prelexical") processes in word recognition. Because our results do not provide a strong basis for distinguishing among such accounts, we will not review the relative merits of them here. Instead, we close by pointing towards several broader theoretical issues that we believe are too often ignored, and yet will ultimately prove critical to the evaluation of these accounts. First, with rare exception, accounts of long-term morphological priming ignore the broader literature on repetition priming and implicit memory. This is unfortunate, as phenomena such as pseudoword priming and perceptual specificity effects are likely to provide interesting and valuable constraints for accounts of morphological priming (see Rueckl, 2002, for discussion). Second, more theoretical attention should be paid to the question of how word recognition processes come to be morphologically structured. To us, an account that attempts to describe the representations and processes employed in skilled reading without attempting to explain how those representations and processes came to be is an incomplete account at best. We agree that there is an important sense in which a model can account for the present results by positing *that* morphology has an early effect on word recognition. However, a more satisfying account would also explain *how* and *why* the word recognition process comes to be organised this way.

REFERENCES

Baayen, R. H., Dijkstra, T., & Schreuder, R., (1997). Singulars and plurals in Dutch: Evidence for a parallel dual route model. *Journal of Memory and Language*, *37*, 94–117.

Bentin, S., & Feldman, L. B. (1990). The contribution of morphological and semantic relatedness to repetition priming at short and long lags: Evidence from Hebrew. *Quarterly Journal of Experimental Psychology*, *42A* (4), 693–711.

Bowers, J. S. (1996). Different perceptual codes support priming for words and pseudowords: Was Morton right all along? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1336–1353.

Brown, J. S., & Carr, T. H. (1993). Limits on perceptual abstraction in reading: Asymmetric transfer between surface forms differing in typicality. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1277–1296.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, *28*, 297–332.

Drews, E., & Zwisterlood, P. (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1098–1116.

Feldman, L. B. (1991). The contribution of morphology to word recognition. *Psychological Research*, *53*, 33–41.

Feldman, L. B. (Ed.). (1995). *Morphological aspects of language processing.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
Feldman, L. B. (2000). Are morphological effects distinguishable from the effects of shared meaning and shared form? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1431–1444.
Feldman, L. B. & Fowler, C. A. (1987). The inflected noun system in Serbo-Croatian: Lexical representation of morphological structure. *Memory and Cognition, 15* (1), 1–12.
Frauenfelder, U. H., & Schreuder, R. (1991). Constraining psycholinguistic models of morphological processing and representation: The role of productivity. In G. E. Booij & J. van Marle (Eds.), *Yearbook of morphology 1991* (pp. 165–183). Dordrecht: Kluwer.
Frost, R., Forster, K., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew? A masked priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1–28.
Frost, R., & Grainger, J. (Eds.). (2000). *Cross-linguistic perspectives on morphological processing.* [Special Issue of Language and Cognitive Processes.] Hove, UK: Psychology Press.
Giraudo, H., & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. *Psychonomic Bulletin and Review*, 127–131.
Gonnerman, L., Devlin, J., Andersen, E. S., & Seidenberg, M. S. (1995). "Morphological" priming without a morphological level of representation. *Journal of the International Neuropsychological Society, 1*, 142.
Henderson, L. (1985). Towards a psychology of morphemes. In A. W. Ellis (Ed.), *Progress in the psychology of language,* vol. 1 (pp. 15–72). Hove, UK: Lawrence Erlbaum Associates Ltd.
Henderson, L., Wallis, J., & Knight, K. (1984). Morphemic structure and lexical access. In H. Bouma & D. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 211–226). Hove, UK: Lawrence Erlbaum Associates Ltd.
Jacoby, L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 21–38.
Kirsner, K., Dunn, J., & Standen, P. (1989). Domain-specific resources in word recognition. In S. Lewandowsky, J. C. Dunn, & K. Kirsner (Eds.), *Implicit memory: Theoretical issues* (pp. 99–122). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
Klein, J. P., & Moeschberger, M. L. (1997). *Survival analysis: Techniques for censored and truncated data.* Berlin: Springer.
Kucera, H., & Francis, W. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.
Laudanna, A., & Burani, C. (1995). Distributional properties of derivational affixes: implications for processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 345–364). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
Lee, E. T. (1992). *Statistical methods for survival data analysis.* New York: John Wiley & Sons.
Lukatela, G., Gligorijevic, B., Kostic, A., & Turvey, M. T. (1980). Representation of inflected nouns in the internal lexicon. *Memory and Cognition, 8*, 415–423.
Manelis, L., & Tharp, D. A. (1977). The processing of affixed words. *Memory and Cognition, 5*, 690–695.
Marslen-Wilson, W., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3–33.
Marsolek, C. J., Kosslyn, S. M., & Squire, L. R. (1992). Form-specific visual priming in the right cerebral hemisphere. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 492–508.
Morton, J. (1969). Interaction of information in word identification. *Psychological Review, 76*, 165–178.

Morton, J. (1979). Facilitation in word recognition: Experiments causing a change in the logogen model. In P. A. Kolers, M. E. Wrostal, & H. Bouma (Eds.), *Processing visible language I* (pp. 259–268). New York: Plenum Press.

Murrell, G. A., & Morton, J. (1974). Word recognition and morphemic structure. *Journal of Experimental Psychology, 102*, 963–968.

Napps, S. E., & Fowler, C. A. (1987). Formal relationships among words and the organization of the mental lexicon. *Journal of Psycholinguistic Research, 16*, 257–272.

Plaut, D. C., & Gonnerman, L. M. (2000). Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing? *Language and Cognitive Processes, 15*, 445–485.

Prinzmetal, W., Treiman, R., & Rho, S. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461–475.

Ratcliff, R., & McKoon, G. (1996). Bias effects in implicit memory tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 754–767.

Raveh, M. & Rueckl, J. (2000). Equivalent effects of inflected and derived primes: Long-term morphological priming in fragment completion and lexical decision. *Journal of Memory and Language, 42*, 103–119.

Roediger, H. L. (1990). Implicit memory: Retention without awareness. *American Psychologist, 45*, 1043–1056.

Roediger, H. L., & McDermott, K. B. (1993). Implicit memory in normal human subject. In H. Spinnler & F. Boller (Eds.), *Handbook of neuropsychology*, (Vol. 8, pp. 63–130). Amsterdam: Elsevier.

Rueckl, J. G. (2002). A connectionist perspective on repetition priming. In J. S. Bowers & C. Marsolek (Eds.), *Rethinking implicit memory* (pp. 67–104). Oxford: Oxford University Press.

Rueckl, J. G., & Mathew, S. (1999). Implicit memory for phonological processes in visual stem completion. *Memory and Cognition, 27*, 1–11.

Rueckl, J. G., & Raveh, M. (1999). The influence of morphological regularities on the dynamics of a connectionist network. *Brain and Language, 68*, 110–117.

Rueckl, J. G., Mikolinski, M., Raveh, M., Miner, C., & Mars, F. (1997). Morphological priming, fragment completion, and connectionist networks. *Journal of Memory and Language, 36*, 382–405

Seidenberg, M., & Gonnerman, L. (2000). Explaining derivational morphology as the convergence of codes *Trends in Cognitive Sciences, 4*, 353–361.

Stolz, J. A., & Feldman, L. B. (1995). The role of orthographic and semantic transparency of the base morpheme in morphological processing. In L. B. Feldman (Ed.). *Morphological aspects of language processing.* (pp. 109–130). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. *Language and Cognitive Processes, 9*, 271–294.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14*, 638–647.

Tenpenny, P. L. (1995). Abstractionist vs. episodic theories of repetition priming and word identification. *Psychonomic Bulletin and Review, 2*, 339–363.

Weldon, M. S. (1991). Mechanisms underlying priming on perceptual tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition, 17*, 526–541.

Weldon, M. S. (1993). The time course of perceptual and conceptual contributions to word fragment completion priming. *Journal of Experimental Psychology: Learning, Memory and Cognition, 19*, 1010–1023.

Winnick, W. A., & Daniel, S. A. (1970). Two kinds of response priming in tachistoscopic recognition. *Journal of Experimental Psychology, 84*, 74–81.