

## Abstractionist versus exemplar-based theories of visual word priming: A subsystems resolution

Chad J. Marsolek

*University of Minnesota, Minneapolis, USA*

Three experiments addressed abstractionist versus exemplar-based theories of the visual representations underlying word priming. Participants first read centrally presented whole words (each displayed in all lowercase or in all uppercase letters), and then they completed laterally presented word stems (each displayed in all lowercase or in all uppercase letters). Word stem completion priming was letter-case specific (greater for same-case primed items than for different-case primed items) when stems were presented directly to the right cerebral hemisphere but not when stems were presented directly to the left cerebral hemisphere. This interaction was not influenced by the typicality of the test stems, but it was observed only for stems composed of letters with visually dissimilar lowercase and uppercase structures (e.g., *bea/BEA*) and not for stems composed of letters with visually similar lowercase and uppercase structures (e.g., *sco/SCO*). In contrast, cued recall was letter-case specific when similar-case or dissimilar-case stems were presented directly to the right hemisphere. Results do not support strongly abstractionist or exemplar-based theories. Instead, they suggest a resolution to these differing perspectives: Relatively independent neural subsystems operate in parallel to underlie abstract-category and specific-exemplar priming of word forms.

The nature of the representations that underlie visual word priming remains controversial. It is fairly well established that representations of visual information per se contribute to long-term repetition priming for words. For example, greater priming is observed following visual encoding of words than following auditory encoding of words, when the priming test tasks are visual (e.g., in word stem completion, Graf, Shimamura, & Squire, 1985; in perceptual

---

Correspondence should be addressed to Chad J. Marsolek, Department of Psychology, University of Minnesota, 75 East River Road, Minneapolis, MN 55455, USA. Email: [chad.j.marsolek-1@umn.edu](mailto:chad.j.marsolek-1@umn.edu)

This research was supported by the National Institute of Mental Health, Grants MH53959 and MH60442; by the McDonnell-Pew Cognitive Neuroscience Center and the Arizona Cognitive Science Program of the University of Arizona; and by the Center for Cognitive Sciences in conjunction with the National Science Foundation (GER 9454163), the Office of the Vice President for Research, and Dean of the Graduate School of the University of Minnesota. I thank Chris Azorson for substantial insights, Jeff Bowers, Tom Carr, Andrew Ellis, Jonathan Grainger, Arne Ostergaard, Martin Pickering, and Bruce Whittlesea for helpful comments on earlier drafts of this article, and Brian Ecker, Brendan Ewald, Erin Stoltz, and Michele Wright for valuable assistance with data collection and analysis. An early portion of this research was presented at the Annual Meeting of the Psychonomic Society, Los Angeles (1995).

identification, Jacoby & Dallas, 1981; in lexical decision, Kirsner & Smith, 1974). However, previous research has supported fundamentally different theories of the visual representations that underlie long-term word-priming effects. In this article, abstractionist and exemplar-based theories are contrasted with a neural subsystems theory that provides a conciliatory view, and new results are reported that support only the latter theory.

## Theories of visual word priming

### *Abstractionist accounts*

Abstractionist theories posit that visual word priming relies on representations of abstract visual information (e.g., Bowers, 1996, 2000; Morton, 1979). The crucial assertion is that visual word representations store only abstract word identities and not specific details such as the letter case of an input word. Note that the claim is not that representations of such specific information do not exist anywhere in the cognitive system. Even strongly abstractionist theories may posit that specific information is stored in episodic memory or explicit memory, independent of visual word representations per se (cf. Forster, Booker, Schacter, & Davis, 1990; Schacter, 1994). However, these specific representations are not hypothesized to be the visual word representations that underlie word recognition in normal reading situations; the only visual word representations per se that exist are abstract. Weak versions of abstractionist theories (e.g., Brown & Carr, 1993) are different in that they posit that specific word representations do exist and participate in normal word priming along with abstract representations (as described below). Thus, the most important criterion for strongly abstractionist theories is the contention that the only kind of representation underlying normal visual word priming stores abstract information; weakly abstractionist theories posit that additional visual word representations store specific information.

Perhaps the most direct evidence for abstractionist accounts comes from Bowers (1996). In one experiment, all of the words were composed of dissimilar-case letters (those with visually dissimilar lowercase and uppercase forms; e.g., rage/RAGE). During an initial encoding phase, some of the words were presented in all lowercase letters, others were presented in all uppercase letters, and still others were presented auditorily. During the subsequent test phase, participants visually identified words presented in all lowercase letters, some of which had been primed during initial encoding and others of which had not been primed. Interestingly, priming in the same letter-case condition (lowercase at encoding, lowercase at test) was equivalent to priming in the different letter-case condition (uppercase at encoding, lowercase at test), indicating that the relevant stored information was abstract with respect to letter case. Indeed, this stored information was very abstract, given that dissimilar-case letters were used. Nonetheless, both same-case and different-case priming were greater than priming in the cross-modality condition (auditory at encoding, lowercase at test), indicating that the stored information was visual in nature. Bowers suggested that, because the visual word priming was abstract, yet pseudoword priming in another experiment (with the same design, except pseudowords were used in place of words) was case specific, orthographic representations in a system devoted to word processing per se supported the abstract word-priming effects. Bowers also suggested that another system (outside of episodic/explicit memory) supports specific priming effects (e.g., for pseudowords); this other system contributes to processing when normal access to orthographic representations is prohibited (e.g., when words are

upside-down or mirror-reversed) but rarely if at all in normal reading situations, thus this theory is relatively more strongly than weakly abstractionist.

The use of lowercase test items may have been important in Bowers (1996), because abstract visual priming may be predicted by whether test items are relatively typical versus relatively atypical. Brown and Carr (1993) noted that abstract priming tends to be found when typical forms are presented at test but specific priming tends to be found when atypical forms are presented (e.g., Jacoby & Hayman, 1987; Kolers, 1973, 1975; Roediger & Blaxton, 1987; see also the exemplar-specific priming trend for Kanji but not Hiragana test words in Bowers & Michita, 1998—children tend to learn Kanji after first learning Hiragana). They also provided further evidence for abstract priming when test words are typed and specific priming when test words are handwritten.

Although this pattern of results appears to require at least a weakly abstractionist account, the pattern can be explained by theories positing that only specific exemplars are stored in memory (e.g., Hintzman, 1986; see also, Logan, 1990; Medin & Schaffer, 1978). Accordingly, due to the frequencies of encountering relatively typical versus relatively atypical instances of words, all of which are stored in memory, a larger number of typical instances than atypical instances are stored per category. Recognition of a typical input takes place primarily through many partial matches to the large number of typical instances to which it is similar, whereas recognition of an atypical input takes place primarily through partial matches to the small number of atypical instances to which it is similar. Recognition of an input during the encoding phase of a priming experiment results in that instance being added to the representations in storage. Thus, storage of an atypical instance (including its details) during the encoding phase impacts recognition of that atypical instance during test (that trace is one of a small number contacted) to a greater degree than storage of a typical instance during the encoding phase impacts recognition of that typical instance during test (that trace is one of a large number contacted). In this way, the typicality of a test word can predict the likelihood of exemplar-specific priming effects.

Therefore, a major concern with abstractionist theories, in general, is that the previous abstract priming results do not unequivocally demand positing abstract visual word representations in addition to, and independent of, specific word representations (cf. Tenpenny, 1995). Exemplar-based theories can account for presumably abstractionist effects. The present study was designed in part to test the above exemplar-based account for abstract priming effects.

### *Exemplar-based accounts*

Exemplar-based theories posit that visual word priming relies on representations of exemplar-specific visual information, at least under some conditions (e.g., Graf & Ryan, 1990; Jacoby, Levy, & Steinbach, 1992; Roediger, 1990). The crucial theoretical assertion is that all visual word representations per se do include specific information such as the letter case of an input word. Often, these representations are described as specific records of prior word-processing events, in which incidental perceptual details may be stored. In this approach, visually specific information is an integral part of the word representations that are normally used during word recognition tasks. It is important to note, however, that the claim is not that visual details always significantly influence word priming. Even purely exemplar-based

theories may posit that specific information is more or less likely to influence processing as a function of the typicality of a stimulus (see above) and the delay since previous processing of the stimulus (e.g., Hintzman, 1986). Also, the same representations that store exemplar information can also conspire to produce abstract prototype effects in some models, either through superimposed representations (e.g., Knapp & Anderson, 1984; McClelland & Rumelhart, 1985) or through summing partial matches to multiple exemplar traces (e.g., Hintzman, 1986). Thus, the most important criterion for exemplar-based theories is the contention that only specific representations are used in word recognition (abstract representations need not exist independently of exemplar representations).

An important type of evidence for exemplar-based theories is letter-case specific word priming. Greater priming is observed when prime words are presented in the same letter case as their corresponding test items than when they are presented in the different letter case (e.g., in word stem completion, Marsolek, Kosslyn, & Squire, 1992; in perceptual identification, Jacoby & Hayman, 1987; in word reading, Masson, 1986). Although significant levels of case-specific priming are not always observed (e.g., Feustel, Shiffrin, & Salasoo, 1983; Scarborough, Cortese, & Scarborough, 1977), trends for case-specific priming are almost always found (Richardson-Klavehn & Bjork, 1988). Also, it appears that case-specific priming is not completely limited to experiments in which atypical forms are presented at test, as case-specific priming can be observed in some conditions with typical fonts and lowercase items at test (e.g., Burgund & Marsolek, 1997; Marsolek et al., 1992; see also Jacoby et al., 1992). Thus, at least one component of the stored information supporting word priming appears to be visually specific.

Note, however, that even strongly abstractionist theories can accommodate case-specific priming effects. These theories need not posit that specific effects should never be observed; representations stored outside of the (abstract) visual word recognition system may support specific effects. For example, "contamination" from involuntary explicit memory (e.g., Richardson-Klavehn, Gardiner, & Java, 1994) may support specificity effects in presumably implicit word-priming experiments (Curran, Schacter, & Bessenoff, 1996; Schacter, 1994), and other specific representations that are not used in normal reading situations may support specific priming effects (Bowers, 1996, 2000). If so, it is possible that abstract representations do exist independently of exemplar representations and do contribute to word priming.

Therefore, a major concern with exemplar-based theories, in general, is that the previous specific priming results do not unequivocally demand positing that only specific representations participate in visual word recognition and priming (cf. Bowers, 2000). Abstract word representations may also exist independent of and in addition to exemplar representations that support the specific effects. The present study was designed in part to test this possibility too.

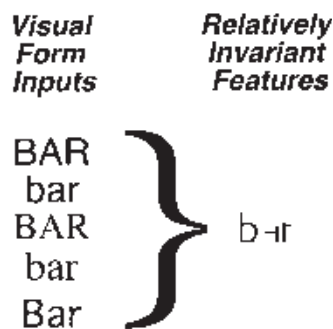
### *Neural subsystems resolution*

The abstractionist versus exemplar-based priming debate remains unsettled, largely because empirical evidence continues to support both perspectives (for reviews from differing perspectives, see Bowers, 2000; Tenpenny, 1995). The resolution offered in this article highlights the advantages of theorizing about the functions of anatomically and physiologically separable brain areas that perform neurocomputationally distinct processes and also conspire to accomplish larger, complex tasks (see Marsolek, 2003). Neurocomputational reasoning

about how brain-like mechanisms can efficiently accomplish certain processes is integrated with implementational evidence for the hypothesized architecture and mechanisms, to supplement purely behavioural evidence and provide strong multiple-level constraints on functional-level theory.

One important goal in visual word recognition is to recognize *abstract categories of word forms* (i.e., to produce the same output representation when different versions of the same word are presented as input). For example, the visual form “bar” and the visual form “BAR” are associated with the same phonological and semantic information in postvisual subsystems. Hence, interactive feedback from postvisual subsystems may cause a visual subsystem to learn to produce the same output for those two inputs in order to efficiently activate appropriate information downstream. What is available in the input to accomplish the goal of activating the same output? Even dissimilar-case words like bar/BAR contain relatively invariant information in their visual inputs that can be used to signal the appropriate common output. The other, more variant, information in the visual inputs is irrelevant and should be ignored to efficiently recognize abstract categories.

Figure 1 schematically displays the set of edges and vertices that is the relatively invariant information for different versions of bar/BAR. This particular set of features, taken as a unique set, suffices for recognition of the category bar/BAR. Even similar words like bat/BAT and ban/BAN have different (albeit similar) sets of features (e.g., bat/BAT requires omission of the right-most horizontal edge in Figure 1, given that the vertices for its connection with the vertical edge on the right are different for t and T; ban/BAN requires an additional vertical edge in place of the right-most horizontal edge in the figure, given that n and N share two parallel vertical edges but not a horizontal edge). Note that virtually any two arbitrarily paired two-dimensional shapes with the complexity level of English forms will share some subset of features in this way. For example, “BAR” and “dog” share features (an enclosed space in the lower left, a y-vertex about two-thirds from the left and halfway up, an enclosed space in the upper right), but because those two shapes are not associated with common phonological and semantic information in postvisual systems, the features shared between them would not be learned as a set that signals a category (unlike the features shared between “BAR” and “bar”). This point is important because Bowers and Michita (1998) demonstrated abstract (yet visual) priming between very dissimilar Kanji and Hiragana



**Figure 1.** The relatively invariant visual features (on the right) that are common to different versions of the same word (on the left) and, as a set, only to different versions of that word. See text for explanation.

versions of the same words in Japanese. The different versions of the same word are complex enough that a unique set of relatively invariant features could be learned between them.

Another important goal in visual word recognition is to recognize *specific exemplars of word forms* (i.e., to produce different output representations when different versions of the same word are presented as input). For example, the visual forms “bar”, “BAR”, and “bar” are different exemplars that can be represented as such. Different exemplars can be associated with distinctive information in postvisual subsystems (e.g., words printed in certain fonts or letter cases can signal something special about them, signatures and handwriting can signal the identities of writers, etc.). Hence, interactive feedback from postvisual subsystems may cause a visual subsystem to learn to distinguish specific exemplars. What is available in the input to accomplish the goal of activating different outputs? The visually distinctive information for a specific exemplar tends not to be found in a subset of features of any one input form, but instead in complex, undifferentiated structures that are close in size to the wholes of any one input. Figure 2 illustrates the distinctive holistic information needed to differentiate exemplars in the abstract category of bar/BAR.

Critically, the useful strategies for abstract-category and specific-exemplar recognition are contradictory in nature. To efficiently recognize a category, it is useful to represent sub-whole *features or parts* of inputs independently as such, given that it is useful to become sensitive to some features or parts of any one input form (the relatively invariant information), but not to the others (all other information). For evidence, see Marsolek (1995). In contrast, to efficiently recognize an exemplar, it is useful to represent complex *whole-based* structures, without representing sub-whole features independently as such; representing the sub-whole features for a category would circumvent the goal of distinguishing the exemplars in a category. For evidence, see Marsolek, Schacter, and Nicholas (1996). A single mechanism should not be able to effectively accomplish both goals through the use of the same representations; thus relatively independent subsystems may have developed to accomplish these goals more effectively than a unified mechanism. For further reasoning and evidence from neural network modeling, see Marsolek and Burgund (1997). Thus, an abstract visual-form subsystem is hypothesized to perform features-based processing to recognize abstract categories of forms, and a specific visual-form subsystem is hypothesized to perform whole-based processing to recognize specific exemplars of visual forms.

<b>Visual Form Inputs</b>	<b>Visually Distinctive Wholes</b>
BAR }	BAR
bar }	bar
BAR }	BAR
bar }	bar
Bar }	Bar

**Figure 2.** The visually distinctive whole-based information (on the right) that differentiates exemplars in the same abstract category (on the left), as well as other exemplars. See text for explanation.

In support of the neural subsystems theory, an abstract–category subsystem appears to operate more effectively than a specific–exemplar subsystem in the left cerebral hemisphere, whereas a specific subsystem appears to operate more effectively than an abstract subsystem in the right cerebral hemisphere (e.g., Marsolek et al., 1992). Letter–case abstract priming is observed when test items are presented directly to the left hemisphere, through brief exposures in the right visual field. In contrast, letter–case specific priming is observed when test items are presented directly to the right hemisphere, through brief exposures in the left visual field. When visual information is presented directly to one hemisphere, subsystems in that hemisphere are given both representational–quality and initiation time advantages over subsystems in the other hemisphere. For example, neuronal firing rates (e.g., Gross, Rocha–Miranda, & Bender, 1972) and amplitudes of functional magnetic resonance signals (Tootell, Mendola, Hadjikhani, Liu, & Dale, 1998) are greater following contralateral than ipsilateral visual stimulation. Also, behavioural performance in some tasks (sometimes in accuracy, not always in response time) is greater when visual comparison items are presented in the same visual fields than when they are presented in different visual fields (e.g., Dimond, Gibson, & Gazzaniga, 1972; Marsolek, Nicholas, & Andresen, 2002). Thus, lateralized presentations give the subsystems in one hemisphere advantages in guiding postvisual processing. The results described above indicate that the characteristic processing of one hypothesized subsystem (i.e., case–abstract priming) is observed when subsystems in the left hemisphere are advantaged by the visual input, whereas evidence for the characteristic processing of the other hypothesized subsystem (i.e., case–specific priming) is observed when subsystems in the right hemisphere are advantaged. Given this interaction, abstract and specific subsystems appear to operate at least relatively independently, with different relative efficiencies in the hemispheres.

It should be noted that the neural subsystems theory is supported by other kinds of evidence as well. Serotonin levels in the brain (Burgund, Marsolek, & Luciana, 2003) and neuroimaging patterns (Buckner et al., 1995) dissociate word priming in these subsystems, and their neurocomputational properties differ (Marsolek & Burgund, 1997). However, critical predictions from the three theoretical approaches to visual word priming remain to be tested.

### Critical untested predictions

Recall that ruling out exemplar–based theories is difficult because they can account for abstract priming effects, at least under restricted conditions. These restricted conditions lead to the following important predictions. As described above, even a strongly exemplar–based theory can account for abstract word priming when the test items are typical instances for a category. Storage of a typical instance during encoding should have little more impact on recognition of that typical instance during test than storage of any other instance during encoding, because the newly stored trace would be one of a large number of typical traces contacted during test. In contrast, case–specific priming may be observed when the test items are atypical instances for a category. Storage of an atypical instance during encoding should have a relatively large impact on recognition of that atypical instance during test; the newly stored trace would be one of a small number of atypical traces contacted during test. This reasoning applies especially well for words that have different–case versions that are visually

dissimilar (e.g., bar/BAR). In such a category, representations of the lowercase and uppercase exemplars would be dissimilar enough for an uppercase test item to contact uppercase (atypical) traces more strongly than lowercase (typical) traces. However, this reasoning should not apply well for words that have highly similar different-case versions and that are presented in a typical font (e.g., cow/COW). In such a category, representations of lowercase and uppercase exemplars would be similar enough that an uppercase test item would contact lowercase (typical) traces nearly as well as uppercase (atypical) traces. Accordingly, case-specific priming should be observed when the uppercase versions of dissimilar-case words are repeated, but not in the other priming conditions, and this specific priming effect should be produced by the same system that underlies any observed abstract priming effects.

Recall also that ruling out abstractionist theories is difficult because (abstract) word representations may not be the only ones accessed during priming tests. This possibility leads to important predictions from such a theory. As described above, even strongly abstractionist theories may posit that case-specific priming can occur when explicit memory representations or other specific representations that reside outside the (abstract) visual word-recognition system contribute to the observed priming. If so, however, any observed case-specific priming should be equivalent in magnitude for dissimilar-case and similar-case stimuli. There is no a priori reason to expect that the representations that reside outside the word recognition system (e.g., explicit memory for the letter case of words; Kirsner, 1973) should treat dissimilar-case and similar-case items differently; letter-case information should be stored for both.

In contrast, the neural subsystems theory generates different predictions. First, case-abstract priming should be observed from an abstract-category subsystem when test items are presented directly to the left hemisphere, for *both* dissimilar-case and similar-case stimuli. With both kinds of stimuli, priming of the relatively invariant information in one exemplar should benefit subsequent processing of any exemplar in its abstract category, producing equivalent same-case and different-case priming. Second, case-specific priming should be observed from a specific-exemplar subsystem when dissimilar-case test items are presented directly to the right hemisphere, but not necessarily when similar-case test items are presented. For dissimilar-case items, priming of the specific whole-based information in one exemplar (e.g., "BAR") should not benefit subsequent processing of a different-case exemplar in that category (e.g., "bar") due to the poor overlap of specific whole-based information. But, for similar-case items, priming of the specific whole-based information in one exemplar (e.g., "COW") may benefit subsequent processing of even a different-case exemplar (e.g., "cow"), given that the overlap of whole-based information is substantial and given that the relevant shape representations are size invariant (for a review of such evidence, see Logothetis & Sheinberg, 1996). Thus, the predictions are that case-specific priming should be observed for dissimilar-case items presented directly to the right hemisphere at test, but case-abstract priming should be observed in the other conditions.

## EXPERIMENT 1

In this experiment, letter-case-abstract and letter-case-specific word priming were measured. During initial encoding, participants read whole words that were presented in all lowercase or all uppercase letters in the central visual field. During subsequent test, they completed lowercase or uppercase word stems that were presented directly to the left or right hemispheres

(briefly in the right or left visual fields). Half of the stems were composed of letters with dissimilar lowercase and uppercase structures, and the other half were composed of similar-case letters. The three kinds of theory make different predictions, as explicated above.

## Method

### *Participants*

A total of 64 male students at the University of Arizona volunteered to participate for course credit (half in the dissimilar-case group and half in the similar-case group). All participants were right-handed, as measured through the Edinburgh Handedness Inventory (Oldfield, 1971); the mean laterality quotient was .68 (range: 1.00–.22). Exclusively right-handed male participants were tested because they tend to exhibit larger and more consistent functional hemispheric asymmetries than do female and left-handed male participants (e.g., Hellige, 1993; Springer & Deutsch, 1998). In addition, no participant was involved in more than one experiment reported in this article.

### *Materials*

Two sets of 96 English words were selected from Webster's Vest Pocket Dictionary (1989), with the constraints that the initial three letters (i.e., the stem) of each word were unique among the set of words chosen and could be completed to form at least 10 words that were entries in the dictionary. With the ratings and cluster analyses reported in Boles and Clifford (1989), the alphabet was median-split into two groups of 13 letters each: those with dissimilar lowercase and uppercase structures (A/a, B/b, D/d, E/e, F/f, G/g, H/h, L/l, M/m, N/n, Q/q, R/r, T/t) and those with similar case structures (C/c, I/i, J/j, K/k, O/o, P/p, S/s, U/u, V/v, W/w, X/x, Y/y, Z/z). With this information, one of the two sets of 96 words had the additional constraint that each three-letter stem contained only dissimilar-case letters, and the other set of 96 words was constrained so that at least two letters of each three-letter stem contained similar-case letters. These groups of critical words were labelled dissimilar-case and similar-case groups; the dissimilar-case items were used for half of the participants, and the similar-case items were used for the other half of the participants. The overall mean frequency of occurrence for the words was 82.5 per million (Francis & Kucera, 1982).

Sixteen counterbalancing lists of six words each were created for each of the two word groups. Each list was balanced for word frequency, the number of words that could be completed from the stem of each word, and the unprimed probability that the stem of each word would be completed to form that word according to pilot measurements.

An additional set of 24 words was selected in the same way, but without restriction on the number of dissimilar-case or similar-case letters in their stems. The stems for these words were used for practice stem completion. Also, five additional words (three at the beginning and two at the end of each encoding list) were used as fillers to attenuate primacy and recency effects.

In order to ensure that the lowercase test stimuli used in this study were more typical than their uppercase counterparts, judgements were collected from 16 participants (none of whom were included in the main experiments reported in this article). The procedure used to collect typicality judgments was the same as that used in Experiment 2 of Brown and Carr (1993). Counterbalanced samples of the test stems used in this study were presented, printed in their lowercase and uppercase versions (in the same font and size as those used in the present experiments). Raters were asked to compare the lowercase and uppercase versions of the samples for typicality or representativeness, using the range of surface forms encountered in all of their reading experiences as a basis for judgement (the wording for these instructions was modelled after that used by Brown & Carr). In these ratings, the lowercase stems were chosen as

more typical with greater frequency (94%) than the uppercase stems (6%), in a highly significant difference ( $p < .00001$ ).

Stimuli were presented on an AppleColor High Resolution RGB Monitor with a Polaroid CP-50 Filter placed over it to reduce glare. Presentations were controlled by a Macintosh II computer. The letters were presented in black against a white background in a 24-point bold Helvetica font, and the fixation dot (subtending  $0.23^\circ$  of visual angle) was a round bullet in that font. Whole words were presented in the centre of the display during initial encoding, and word stems were presented laterally at test such that the centre of each three-letter stem was always  $2.5^\circ$  from the centre of the display, and the inner edge was never less than  $1.5^\circ$  from the centre of the display. These eccentricities virtually assured that stimuli were presented directly to only one hemisphere. It is not yet clear whether any nasotemporal overlap exists along the vertical meridian of the visual field (Brysbaert, 1994), however even if a retinal midline of approximately  $1^\circ$  in width projects directly to both hemispheres (Bunt, Mickler, & Johanson, 1977), the presentations used here would have been lateralized. When instructed to fixate on a central point, participants have been shown to (mis-)fixate  $0.5^\circ$  or more away from that point on 12% of trials in divided-visual-field presentations (Jordan, Patching, & Milner, 1998) but more than  $1^\circ$  from that point on less than 1% of trials (Jordan et al., 1998, Fig. 1). (These data were collected during a word recognition task in which accuracy was the behavioural dependent variable.) Given that the inner edge of a stimulus was never less (and often farther) than  $1.5^\circ$  from the fixation point in the present experiments, a part of a stimulus may have fallen just within the retinal midline on very few trials, if any (no more than 1%). In order to help constrain the participants' attention to the portion of the display in which stimuli were presented, all stimuli were presented within a continuous  $10 \times 4$ -cm white window surrounded by grey. The participants' head positions were stabilized with a chinrest so that their eyes were approximately 50 cm from the monitor.

### *Procedure*

Each participant was tested individually. Each experimental session had an initial encoding phase and a subsequent test phase, separated by about 6 minutes.

In the initial encoding phase, participants silently read 48 words presented one at a time (plus 5 filler words, 3 at the beginning and 2 at the end, to attenuate primacy and recency effects). They rated how much they liked or disliked each word on a 5-point scale (1 = dislike very much; 5 = like very much), especially considering the meanings associated with the words. Half of the words were presented in all lowercase letters, and half were presented in all uppercase letters. To increase subsequent priming effects, the set of words was presented twice in succession, with the same instructions for each iteration but with a different pseudorandom order for each.

Each trial in the encoding phase was initiated by the presentation of the fixation dot in the centre of the display for 500 ms. Immediately after the fixation dot, a word appeared centrally for 3 s, followed by a blank screen. Participants pressed a number key on the keyboard corresponding to their like/dislike rating response, and they were instructed to respond only after the word disappeared from the display. The next trial began 1 s after a response was registered.

Each participant read the 48 words from 8 of the 16 (either dissimilar-case or similar-case) critical word lists. These 48 words were presented in different pseudorandom orders across participants. Orders were random with the constraints that no more than three words appeared consecutively in the same letter case, and no more than three words appeared consecutively whose stems during test would be presented in the same visual field or in the same or different letter case compared with their prime words during encoding.

In the subsequent test phase, participants completed 96 word stems presented one at a time (plus 24 practice stems). The 96 presentations were divided into four blocks of 24 trials each, with a short break allowed between blocks. Each block contained 12 primed stems (those from two of the counterbalancing

lists, with stems from one list presented in the left visual field and stems from the other list presented in the right visual field) and 12 unprimed stems (those from another two of the counterbalancing lists, with stems from one list presented in the left visual field and stems from the other list presented in the right visual field). Participants were instructed that each stem was the beginning of an English word and that they were to mentally add one or more letters to the end of it to make the first English word that came to mind, excluding proper nouns whenever possible. A practice session of 24 unprimed stem-completion trials (conducted in the same manner as the test trials) intervened between the encoding and test phases. This session was included to give participants practice with the test procedure before the experimental trials began.

Each trial in the test phase was initiated by the presentation of the fixation dot in the centre of the display for 500 ms. Participants were emphatically instructed to focus attention on the dot the entire time it appeared and not to guess which side the next stem may appear. Immediately after the dot disappeared, a stem appeared directly to the left or right of the centre of the display for 183 ms, followed by a blank screen. Participants spoke aloud word completions (which the experimenter recorded) as soon as they thought of them. The next trial began 1 s after a vocal response was registered by a microphone connected to the computer keyboard.

Each participant completed the 96 stems from the 16 (either dissimilar-case or similar-case) critical word lists. These stems were presented in different pseudorandom orders for each participant. The orders were random with the constraints that no more than three stems that had been primed or unprimed appeared consecutively, and no more than three stems appeared consecutively in the same visual field or in the same letter case.

Therefore, 96 word stems were presented to each participant, half primed and half unprimed. The 48 primed stems were presented such that 6 stems represented each of the eight cells formed by combining type of priming (same letter case vs. different letter case), hemisphere of direct test presentations (left vs. right), and letter case of test stems (lowercase vs. uppercase). One additional independent variable, letter-case similarity of the test stems (dissimilar vs. similar), was manipulated between participants. Counterbalancing assured that each dissimilar-case stem represented each combination of the other independent variables an equal number of times across participants, and likewise each similar-case stem represented each combination of the other independent variables an equal number of times across participants.

## Results

In all experiments reported in this article, a response word was scored as one of the critical word completions only if it was exactly the same as the complete word associated with the stem presented in that trial. According to this strict scoring criterion, no plural forms, past tense forms, or other changes from a critical word completion were accepted. In addition, critical-word completion rates were conditionalized, such that only trials in which the stems were accurately perceived by participants were included in the calculations of critical-word completion rates. These analyses of conditionalized completion rates did not differ qualitatively from analyses of unconditionalized completion rates, largely because the stems were perceived accurately in large percentages of trials (90.1%, 90.0%, and 92.8% for Experiments 1, 2, and 3, respectively). Also, valid analyses of response times for critical-word completions were prohibited; many cells in the design did not have observations in which a critical word was produced.

Two repeated measures analyses of variance (ANOVAs) were conducted, one using participants as the random variable (denoted  $F_1$  below) and the other using stems as the random

variable (denoted  $F_2$  below). To analyse priming effects directly, difference scores were used as the dependent measure. Thus, for each participant or for each stem, the critical-word completion rates for unprimed trials were subtracted from the critical-word completion rates for primed trials. The completion rates for unprimed trials were 15.6% and 13.3% for lower-case and uppercase stems presented directly to the left hemisphere and 17.1% and 16.7% for lowercase and uppercase stems presented directly to the right hemisphere, and these baseline rates did not differ significantly across test hemisphere or letter case of test stems for either dissimilar-case stems or similar-case stems ( $p$ s > .15). Appropriate subtractions were calculated for each participant or for each stem such that the completion rates for the four unprimed conditions (crossing test hemisphere with letter case of test stems) were subtracted from the completion rates for the analogous primed conditions. Thus, the dependent variable allowed for analysis of a direct measure of priming per se. Four independent variables were examined; within-participants/items variables were type of priming (same letter case vs. different letter case), hemisphere of direct test presentations (left vs. right), and letter case of test stems (lowercase vs. uppercase), and the between-participants/items variable was letter-case similarity of the test stems (dissimilar vs. similar).

Figure 3 displays the critical-word completion rates from this experiment. The most important result in the analyses of priming scores was that the three-way interaction between case similarity of test stems, type of priming, and test hemisphere was significant,  $F_1(1, 62) = 8.16$ ,  $MSE = 348.6$ ,  $p < .01$ ;  $F_2(1, 190) = 10.5$ ,  $MSE = 242.6$ ,  $p < .01$ . For dissimilar-case trials (left side of Figure 3), same-case priming (26.5%) was significantly greater than different-case priming (14.1%) when stems were presented directly to the right hemisphere,  $F_1(1, 124) = 13.9$ ,  $MSE = 354.2$ ,  $p < .001$ ;  $F_2(1, 380) = 18.8$ ,  $MSE = 245.0$ ,  $p < .001$ , for the simple effect contrasts, but same-case priming (16.7%) was not greater than different-case priming (23.1%) when stems were presented directly to the left hemisphere,  $F_1(1, 124) = 3.62$ ,  $MSE = 354.2$ ,  $p < .06$ ;  $F_2(1, 380) = 5.85$ ,  $MSE = 245.0$ ,  $p < .05$ , for the simple effect contrasts. This

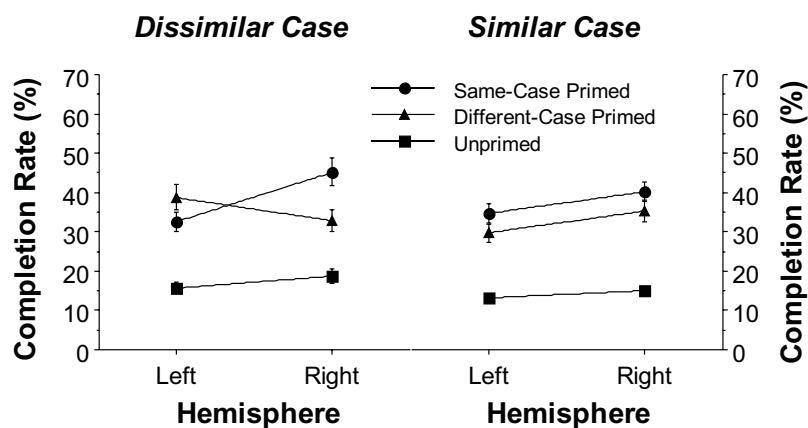


Figure 3. Results from Experiment 1, in which a relatively deep encoding task was used. Mean critical-word stem completion rates are depicted as functions of hemisphere of direct test presentation of the stems (left vs. right), type of initial encoding of the critical word completions (same-case primed vs. different-case primed vs. unprimed), and letter-case similarity of the stimuli (dissimilar-case vs. similar-case). Error bars indicate standard errors of the mean.

interaction between type of priming and test hemisphere was significant,  $F_1(1, 62) = 16.1$ ,  $MSE = 348.6$ ,  $p < .001$ ;  $F_2(1, 190) = 23.0$ ,  $MSE = 242.6$ ,  $p < .001$ , for the interaction contrasts. However, for similar-case trials (right side of Figure 3), the interaction between type of priming and test hemisphere did not approach significance,  $F_1 < 1$ ;  $F_2 < 1$ , for the interaction contrasts. This pattern of results did not differ depending on letter case of test stems, as tested in the four-way interaction,  $F_1 < 1$ ;  $F_2 < 1$ .

The other significant effects in these analyses were the following (all other  $ps > .13$ ). First, same-case priming (22.5%) was generally greater than different-case priming (18.5%),  $F_1(1, 62) = 5.71$ ,  $MSE = 359.8$ ,  $p < .05$ ;  $F_2(1, 190) = 10.5$ ,  $MSE = 247.3$ ,  $p < .01$ , for the main effect of type of priming. Second, priming was generally greater for stems presented in uppercase letters (22.4%) than in lowercase letters (18.6%),  $F_1(1, 62) = 4.72$ ,  $MSE = 399.4$ ,  $p < .05$ ;  $F_2(1, 190) = 5.97$ ,  $MSE = 958.2$ ,  $p < .05$ , for the main effect of letter case of test stems. Third, same-case priming was greater than different-case priming when stems were presented directly to the right hemisphere (25.8% vs. 17.1%, respectively), but not when stems were presented directly to the left hemisphere (19.2% vs. 19.8%, respectively),  $F_1(1, 62) = 7.98$ ,  $MSE = 348.6$ ,  $p < .01$ ;  $F_2(1, 190) = 12.5$ ,  $MSE = 242.6$ ,  $p < .01$ , for the interaction between type of priming and test hemisphere.

Finally, it should be noted that the most important conclusions from this experiment did not differ between the analyses of priming scores (reported above) and analyses of unsubtracting critical-word completion rates, which used type of initial encoding (same-case primed vs. different-case primed vs. unprimed) as an independent variable in place of type of priming (same letter case vs. different letter case). In both, the three-way interaction between case similarity of test stems, type of priming, and test hemisphere was significant ( $ps < .01$ ); and this pattern did not differ depending on letter case of test stems in a four-way interaction ( $ps > .51$ ).

## Discussion

As predicted, both case-specific priming and case-abstract priming were observed, in a pattern of results that supports the neural subsystems theory but does not support strongly abstractionist or exemplar-based theories. Case-specific priming was observed when dissimilar-case test items were presented directly to the right hemisphere, and case-abstract priming was observed in the other conditions, consistent with the neural subsystems theory. The observed case-specific priming was not affected by the typicality of test items (lowercase versus uppercase stems, verified by ratings), which is inconsistent with exemplar-based theories that rely on similarity to stored instances. Also, specific versus abstract priming differed depending on the hemisphere of direct test presentations, which is inconsistent with exemplar theories that posit a single system supporting both priming effects. In addition, the observed case-specific priming was found for dissimilar-case stems but not for similar-case stems, inconsistent with strongly abstractionist theories that posit additional specific representations (e.g., in explicit memory) to explain specificity effects.

In a marginally significant or significant difference, different-case priming was greater than same-case priming when dissimilar-case test items were presented directly to the left hemisphere. Because such a difference has not been observed in any of several previous experiments using similar procedures (Burgund & Marsolek, 1997; Koivisto, 1995, 1996; Marsolek

& Andresen, 2003; Marsolek & Hudson, 1999; Marsolek et al., 1992, 1996; Marsolek, Squire, Kosslyn, & Lulenski, 1994), one purpose for Experiment 2 was to test whether this difference would be significant in a new set of data.

A potential difficulty in interpreting the results from Experiment 1 is that the initial encoding task (like/dislike judgements) required substantial postvisual processing of semantic information. This should not matter according to the neural subsystems theory, because depth of encoding ( Craik & Lockhart, 1972) should mainly affect postvisual processing. Visual-form recognition (and resultant priming in visual-form subsystems) should occur upstream from semantic processing and hence should not be greatly influenced by the additional processing. However, the encoding task should matter according to other theories positing that a relatively visual (or orthographic) encoding task is necessary to obtain normal visual word-priming effects (Curran et al., 1996; Graf & Ryan, 1990). For this reason, a typical shallow encoding task was used in Experiment 2 to test whether a different pattern of results would be obtained. For example, greater case-specific priming may be observed, and this additional priming component may have different properties from those of the case-specific priming observed in Experiment 1.

Experiment 2 also allowed for an additional test of the possibility that explicit memory contributed to the priming effects in Experiment 1. Given that relatively deep encoding tasks lead to greater explicit memory effects than do relatively shallow encoding tasks (e.g., Craik & Tulving, 1975; Hyde & Jenkins, 1973), any results from Experiment 1 that are not replicated in Experiment 2 could be due to involuntary explicit memory. In particular, negligible case-specific priming in Experiment 2 would suggest that the significant case-specific priming in Experiment 1 may have been due to explicit memory.

## EXPERIMENT 2

This experiment was conducted in the same manner as that of Experiment 1, except that participants counted the number of vowels in each word during initial encoding. (This task encouraged shallow encoding of words but probably not any creation of new explicit memories for the words and their letter cases during encoding.) The prediction from the neural subsystems theory is the same as that in Experiment 1: Case-specific priming should be observed for dissimilar-case items presented directly to the right hemisphere at test, whereas case-abstract priming should be observed in the other conditions. However, theories positing that depth of encoding should affect case-specific priming would predict either smaller (many strongly abstractionist theories) or larger (Curran et al., 1996; Graf & Ryan, 1990) case-specific priming effects in this experiment than in Experiment 1. Moreover, the predictions from abstractionist and exemplar-based theories outlined in the Introduction, but unsupported in Experiment 1, were tested a second time.

### Method

#### *Participants*

A total of 64 male students at the University of Arizona volunteered to participate for course credit (half in the dissimilar-case group and half in the similar-case group). All were right-handed, as measured

through the Edinburgh Handedness Inventory (Oldfield, 1971); the mean laterality quotient was .70 (range: 1.00–.22).

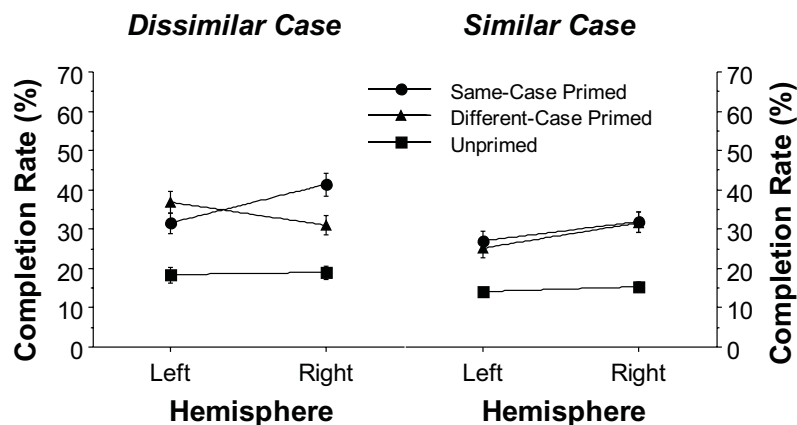
### Materials and procedure

The materials and procedure were the same as those used in Experiment 1, with the exception that participants were instructed to count the number of vowels in each word during the initial encoding phase. They pressed a number key on the keyboard reflecting their count after each word disappeared from the computer display in each trial.

### Results

As in Experiment 1, two 4-way repeated measures ANOVAs were conducted to analyse priming effects, one by participants (denoted  $F_1$  below) and the other by items (denoted  $F_2$  below). The critical-word completion rates for unprimed trials were 16.3% and 16.0% for lowercase and uppercase stems presented directly to the left hemisphere and 19.6% and 14.6% for lowercase and uppercase stems presented directly to the right hemisphere, and these baseline rates did not differ significantly across test hemisphere or letter case of test stems for either dissimilar-case stems or similar-case stems ( $ps > .12$ ). Thus, priming score was the dependent variable, calculated as in Experiment 1. The within-participants/items independent variables were type of priming (same letter case vs. different letter case), hemisphere of direct test presentations (left vs. right), and letter case of test stems (lowercase vs. uppercase). The one between-participants/items variable was letter-case similarity of the test stems (dissimilar vs. similar).

Figure 4 displays the critical-word completion rates from this experiment. As in Experiment 1, the most important result in the analyses of priming scores was that the three-way interaction between case similarity of test stems, type of priming, and test hemisphere was



**Figure 4.** Results from Experiment 2, in which a relatively shallow encoding task was used. Mean critical-word stem completion rates are depicted as functions of hemisphere of direct test presentation of the stems (left vs. right), type of initial encoding of the critical word completions (same-case primed vs. different-case primed vs. unprimed), and letter-case similarity of the stimuli (dissimilar-case vs. similar-case). Error bars indicate standard errors of the mean.

significant,  $F_1(1, 62) = 6.02$ ,  $MSE = 401.3$ ,  $p < .05$ ;  $F_2(1, 190) = 12.1$ ,  $MSE = 283.5$ ,  $p < .001$ . For the dissimilar-case trials (left side of Figure 4), same-case priming (22.4%) was significantly greater than different-case priming (12.1%) when stems were presented directly to the right hemisphere,  $F_1(1, 124) = 8.64$ ,  $MSE = 393.8$ ,  $p < .01$ ;  $F_2(1, 380) = 22.2$ ,  $MSE = 278.3$ ,  $p < .001$ , for the simple effect contrasts, but same-case priming (13.3%) was not greater than different-case priming (18.6%) when stems were presented directly to the left hemisphere,  $F_1(1, 124) = 2.29$ ,  $MSE = 393.8$ ,  $p > .13$ ;  $F_2(1, 380) = 1.72$ ,  $MSE = 278.3$ ,  $p > .19$ , for the simple effect contrasts. This interaction between type of priming and test hemisphere was significant,  $F_1(1, 62) = 9.73$ ,  $MSE = 401.3$ ,  $p < .01$ ;  $F_2(1, 190) = 17.8$ ,  $MSE = 283.5$ ,  $p < .001$ , for the interaction contrasts. However, for similar-case trials (right side of Figure 4), the interaction between type of priming and test hemisphere did not approach significance,  $F_1 < 1$ ;  $F_2 < 1$ , for the interaction contrasts. This pattern of results did not differ depending on letter case of test stems, as tested in the four-way interaction,  $F_1(1, 62) = 1.24$ ,  $MSE = 397.9$ ,  $p > .25$ ;  $F_2 < 1$ .

Only one other effect approached significance in these analyses (all other  $ps > .11$ ). Same-case priming was greater than different-case priming when stems were presented directly to the right hemisphere (19.5% vs. 14.3%, respectively), but not when stems were presented directly to the left hemisphere (13.1% vs. 14.8%, respectively) in a marginally significant effect by participants,  $F_1(1, 62) = 3.84$ ,  $MSE = 401.3$ ,  $p < .06$ , and in a significant effect by items,  $F_2(1, 190) = 6.20$ ,  $MSE = 283.5$ ,  $p < .05$ , for the interaction between type of priming and test hemisphere.

Finally, it should be noted that the most important conclusions from this experiment did not differ between the analyses of priming scores (reported above) and analyses of unsubtracted critical-word completion rates including type of initial encoding (same-case primed vs. different-case primed vs. unprimed) as an independent variable in place of type of priming (same letter case vs. different letter case). In both, the three-way interaction between case similarity of test stems, type of priming, and test hemisphere was significant ( $ps < .05$ ); and this pattern did not differ depending on letter case of test stems in a four-way interaction ( $ps > .17$ ).

## Discussion

The important results from Experiment 1 were replicated in this experiment. Case-specific priming was observed when dissimilar-case stems were presented directly to the right hemisphere, and case-abstract priming was observed in the other conditions, with typicality of the test stimuli not influencing the observed priming. This pattern of results is consistent with the neural subsystems theory but not with strongly abstractionist or exemplar-based theories.

It should be noted that, unlike the marginally significant or significant difference observed in Experiment 1, different-case priming was not significantly greater than same-case priming when dissimilar-case test items were presented directly to the left hemisphere in this experiment. This finding from Experiment 2 is in line with results from many previous experiments using similar procedures (Burgund & Marsolek, 1997; Koivisto, 1995, 1996; Marsolek & Andresen, 2003; Marsolek & Hudson, 1999; Marsolek et al., 1992, 1994, 1996), unlike the previous finding from Experiment 1.

The only procedural difference between Experiments 1 and 2 was the depth of initial encoding. Apparently, the important finding of case-specific priming when dissimilar-case stems are presented directly to the right hemisphere and case-abstract priming in the other conditions does not depend on processing that occurs after visual-form recognition during the encoding task. Also, given that depth of encoding normally influences explicit memory (e.g., Craik & Tulving, 1975; Hyde & Jenkins, 1973), it is unlikely that explicit memory supports the important priming effects. Thus, inconsistent with some strongly abstractionist theories, explicit memory may not support case-specific priming. This conclusion complements another conclusion from the priming results: If explicit memory had supported the case-specific priming in right-hemisphere test presentations in both experiments, case-specific priming should have been observed for both dissimilar-case and similar-case stems. However, it was not found for similar-case stems, and thus explicit memory apparently does not support it.

An important assumption underlying this reasoning is that it is possible to obtain case-specific explicit memory in right-hemisphere test presentations with the particular similar-case stems that were used in Experiments 1 and 2. However, if those stems were so similar that they could not allow explicit memory to differentially store the lowercase and uppercase versions, then the reasoning would not hold; there would have been no opportunity for explicit memory to support case-specific priming for those stimuli. Thus, Experiment 3 was conducted in part to test whether case-specific explicit memory can be observed in right-hemisphere test presentations with the similar-case stems used in Experiments 1 and 2. In addition, Experiment 3 was conducted to test another prediction to further test the idea that explicit memory supports case-specific priming. Case-specific priming was observed in right-hemisphere test presentations with dissimilar-case stems but not with similar-case stems in Experiments 1 and 2. In an explicit memory experiment, if case-specific memory in right-hemisphere test presentations is no greater for dissimilar-case stems than for similar-case stems, then explicit memory probably did not underlie the case-specific priming observed in Experiments 1 and 2.

### EXPERIMENT 3

This experiment was conducted in the same manner as that of Experiment 2, except that the test task was word-stem cued recall instead of completing stems to form the first words that came to mind. Participants were asked to use each stem to help them recall a word presented during initial encoding and to try to complete each stem to form such a word; thus explicit memory was measured directly in this experiment. Two main predictions were examined. First, if case-specific cued recall is observed following right-hemisphere presentations of similar-case stems, this would contradict the possibility that explicit memory normally supports case-specific priming effects but was incapable of doing so for the similar-case items in Experiment 2 (perhaps due to idiosyncrasies associated with the particular items and experimental design used). Second, if case-specific cued recall following right-hemisphere test presentations is no greater for dissimilar-case stems than for similar-case stems, unlike the previous pattern of priming results, then explicit memory probably did not underlie the case-specific priming in Experiments 1 and 2.

## Method

### *Participants*

A total of 64 male students at the University of Arizona or the University of Minnesota volunteered to participate for course credit. All were right-handed, as measured through the Edinburgh Handedness Inventory (Oldfield, 1971); the mean laterality quotient was .70 (range: 1.00–30).

### *Materials and procedure*

The materials and procedure were the same as those used in Experiment 2, except that participants were instructed to try to use each test stem as a cue to help them recall a word from the initial encoding phase. They were told that not all of the stems could be completed to form such words, and thus they should try to guess such a word when they could not recollect one. Also, for each of the practice trials, participants reported only the stem itself, because none of the practice stems could have been completed to form previously presented words.

## Results

Two repeated measures ANOVAs were conducted, one using participants as the random variable (denoted  $F_1$ ) and the other using stems as the random variable (denoted  $F_2$ ). The critical-word completion rates for baseline trials were 17.4% and 20.0% for lowercase and uppercase stems presented directly to the left hemisphere and 18.9% and 15.8% for lowercase and uppercase stems presented directly to the right hemisphere, and these rates did not differ significantly across test hemisphere or letter case of test stems for either dissimilar-case stems or similar-case stems ( $p > .35$ ). Thus, “cued recall score” was the dependent variable, calculated in the manner that priming scores were calculated in Experiments 1 and 2. This allowed for greatest comparability across experiments. Within-participants/items independent variables were type of cued recall score (same letter case vs. different letter case), hemisphere of direct test presentations (left vs. right), and letter case of test stems (lowercase vs. uppercase), and the between-participants/items variable was letter-case similarity of the test stems (dissimilar vs. similar).

In the analyses of cued recall scores, the two-way interaction between type of cued recall score and test hemisphere did not reach significance,  $F_1(1, 62) = 1.68$ ,  $MSE = 315.3$ ,  $p > .15$ ;  $F_2(1, 190) = 1.69$ ,  $MSE = 289.5$ ,  $p > .15$ , and the three-way interaction between case similarity of the test stems, type of cued recall score, and test hemisphere did not reach significance,  $F_1(1, 62) = 1.59$ ,  $MSE = 315.3$ ,  $p > .20$ ;  $F_2 < 1$ .

More important, however, was that the a priori predictions that motivated this experiment were tested directly via the following contrasts. Figure 5 displays the cued recall rates from this experiment. Regarding the first main prediction for this experiment, when similar-case stems were presented directly to the right hemisphere, the same-case cued recall score (29.8%) was greater than the different-case cued recall score (18.6%),  $F_1(1, 124) = 12.4$ ,  $MSE = 322.2$ ,  $p < .001$ ;  $F_2(1, 380) = 20.5$ ,  $MSE = 315.8$ ,  $p < .001$ , for the a priori simple effect contrasts. And directly testing the second main prediction for this experiment, when stems were presented directly to the right hemisphere, the difference between the same-case and different-case cued recall scores was no greater when dissimilar-case stems were presented (20.9% vs. 17.5%),  $F_1(1, 124) = 1.16$ ,  $MSE = 322.2$ ,  $p > .25$ ;  $F_2(1, 380) = 1.65$ ,  $MSE = 315.8$ ,

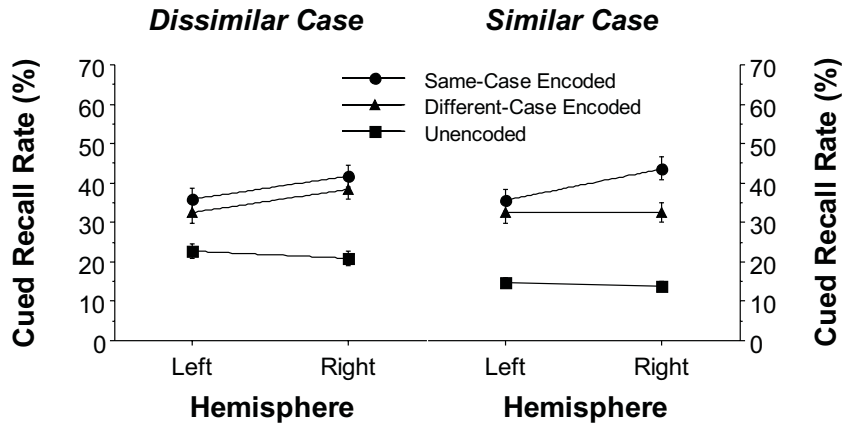


Figure 5. Results from Experiment 3. Mean word-stem cued recall rates are depicted as functions of hemisphere of direct test presentation of the stems (left vs. right), type of initial encoding of the critical-word completions (same-case encoded vs. different-case encoded vs. unencoded), and letter-case similarity of the stimuli (dissimilar-case vs. similar-case). Error bars indicate standard errors of the mean.

$p > .19$ , for the simple effect contrasts, than when similar-case stems were presented (29.8% vs. 18.6%), simple effect contrasts reported above. In fact, that difference was greater with similar-case stems than with dissimilar-case stems in a marginally significant or significant effect,  $F_1(1, 124) = 3.00$ ,  $MSE = 322.2$ ,  $p < .09$ ;  $F_2(1, 380) = 5.25$ ,  $MSE = 315.8$ ,  $p < .05$ , for the a priori interaction contrasts.

The other significant effects were the following (all other  $ps > .08$ ). First, the same-case cued recall score (21.2%) was greater than the different-case cued recall score (15.9%) in a main effect of type of cued recall score,  $F_1(1, 62) = 10.8$ ,  $MSE = 329.2$ ,  $p < .01$ ;  $F_2(1, 190) = 19.3$ ,  $MSE = 342.1$ ,  $p < .001$ . Second, cued recall was greater when stems were presented directly to the right hemisphere (21.7%) than to the left (15.4%),  $F_1(1, 62) = 7.23$ ,  $MSE = 706.4$ ,  $p < .01$ ;  $F_2(1, 190) = 13.5$ ,  $MSE = 1001.9$ ,  $p < .001$ , for the main effect of test hemisphere. Third, cued recall was greater when similar-case stems were presented (21.8%) than when dissimilar-case stems were presented (15.3%),  $F_1(1, 62) = 5.58$ ,  $MSE = 976.8$ ,  $p < .05$ ;  $F_2(1, 190) = 12.2$ ,  $MSE = 1822.1$ ,  $p < .001$ , for the main effect of case similarity of the test stems.

Finally, the most important conclusions from this experiment did not differ between analyses of cued recall scores (reported above) and analyses of unsubtracted critical-word completion rates including type of initial encoding (same-case encoded vs. different-case encoded vs. unencoded) as an independent variable in place of type of cued recall score (same letter case vs. different letter case). In both, the important a priori contrasts were significant ( $ps < .05$ ).

### Combined results (from Experiments 2 and 3)

The most important results from Experiment 3 were that two effects were obtained that were not observed in the analogous conditions of Experiment 2. To directly test these differences between the experiments, two final repeated measures ANOVAs were conducted on the

combined data from Experiments 2 and 3, one by participants (denoted  $F_1$ ) and the other by stems (denoted  $F_2$ ), with experiment as an additional independent variable. Within these ANOVAs, a priori interaction contrasts confirmed that, when similar-case stems were presented directly to the right hemisphere, same-case memory was greater than different-case memory in Experiment 3 (29.8% vs. 18.6%) but not in Experiment 2 (16.6% vs. 16.5%),  $F_1(1, 250) = 5.38$ ,  $MSE = 367.2$ ,  $p < .05$ ;  $F_2(1, 762) = 12.9$ ,  $MSE = 303.1$ ,  $p < .001$ . In addition, a priori interaction contrasts confirmed that, when stems were presented directly to the right hemisphere, the difference between the same-case and different-case cued recall scores was no greater when dissimilar-case stems (20.9% vs. 17.5%) were presented than when similar-case stems were presented (29.8% vs. 18.6%) in Experiment 3, but it was greater when dissimilar-case stems were presented (22.4% vs. 12.1%) than when similar-case stems were presented (16.6% vs. 16.5%) in Experiment 2,  $F_1(1, 250) = 7.06$ ,  $MSE = 367.2$ ,  $p < .01$ ;  $F_2(1, 762) = 17.2$ ,  $MSE = 303.1$ ,  $p < .001$ .

## Discussion

First, case-specific cued recall was observed when similar-case stems were presented directly to the right hemisphere, unlike the case-specific priming results in Experiment 2. Thus, it should have been possible for case-specific priming to be observed for similar-case stems following right-hemisphere test presentations in Experiment 2, if explicit memory normally supports case-specific priming, as suggested by some strongly abstractionist theories. Second, case-specific cued recall following right-hemisphere test presentations was no greater for dissimilar-case stems than for similar-case stems in Experiment 3. (Indeed, it was greater for similar-case stems than for dissimilar-case stems in an unexpected marginally significant or significant difference that does not afford an obvious explanation.) Because this differed from the pattern of priming results in Experiment 2, explicit memory probably did not underlie the case-specific priming in Experiment 2. Taken together, the results from Experiments 2 and 3 do not support the hypothesis that explicit memory supports case-specific priming.

The neural subsystems theory posits instead that case-specific priming is supported by a specific-exemplar subsystem of visual-form recognition operating independently of an abstract-category subsystem of visual-form recognition. This is why specific and abstract priming for dissimilar-case items were dissociated by hemisphere of direct test presentations in Experiments 1 and 2. Also, both of these subsystems can support priming effects independently from explicit memory (probably through small, local synaptic changes in visual cortex; see Marsolek, 2003). This explains why neither subsystem was affected (negatively or positively) by the depth of encoding change between Experiments 1 and 2. However, as argued in Marsolek et al. (1994; see also Marsolek et al., 1996), a specific-exemplar subsystem is one of the many neocortical subsystems that can interact with the hippocampal formation (e.g., McClelland, McNaughton, & O'Reilly, 1995; Squire, 1992) to store new explicit memory traces involving the information normally stored in the neocortical subsystems. In this way, case-specific explicit memory can be produced (as in Experiment 3).

Why was case-specific memory for similar-case items observed in right-hemisphere test presentations when explicit memory was measured (Experiment 3), but not when priming was measured (Experiments 1 and 2)? An important function of the interactions between the hippocampus and neocortical subsystems is to rapidly separate highly similar memory traces,

as is typically needed to differentiate highly similar new episodic memories (for a computational explanation, see O'Reilly & McClelland, 1994), and as should be needed to differentiate lowercase and uppercase versions of similar-case words in such a manner that a case-specific memory effect can be produced. Of course, this effect should rely on interactions with a specific-exemplar subsystem in neocortex, not an abstract-category subsystem, and hence should be greater in right-hemisphere than in left-hemisphere test presentations (as observed in Experiment 3). Without the hippocampal interactions, the overlap between primed and test information in a specific-exemplar subsystem may be so great for similar-case stimuli that it precludes a case-specific priming effect (as observed in Experiments 1 and 2). In other words, "cow" is primed by "COW" as effectively as by "cow", unless the pattern separation ability of the hippocampus is utilized.

### GENERAL DISCUSSION

Two main theoretical approaches have been used to explain visual word priming. On the one hand, strongly abstractionist theories posit that visual word representations are abstract with respect to visual-detail information. They claim that any observed specific priming effects are supported by explicit memory or other representations that do not contribute to normal word recognition. On the other hand, exemplar-based theories claim that only specific representations (including visual details) need be hypothesized. They posit that these representations suffice to support any observed abstract priming effects. The results from this study disaffirm both types of theory and instead support the hypothesis that dissociable neural subsystems underlie visual word recognition: An abstract-category subsystem supports abstract priming effects and operates more effectively than a specific-exemplar subsystem in the left cerebral hemisphere, and a specific-exemplar subsystem supports specific priming effects and operates more effectively than an abstract-category subsystem in the right cerebral hemisphere.

It is important to note that the main conclusions from this study were drawn from analyses using stems and participants as the random variables. Multiple factors can influence the completions generated for different word stems (e.g., Ryan, Ostergaard, Norton, & Johnson, 2001), and how good a particular stem is as a cue for its predetermined critical-word completion varies across stems, thus it is important to test the generalizeability of findings observed with a sample of stems. In addition, it is noteworthy that stem completion priming is preferable to other word priming tasks when investigating hemispheric asymmetries. Strong left-hemisphere advantages are consistently obtained in the perceptual identification task, both in baseline performance of priming experiments (Burgund & Marsolek, 1997; Koivisto, 1995, 1996) and in unprimed identification performance (e.g., Beaumont, 1982, Mishkin & Forgy, 1952; Young, Ellis, & Bion, 1984). Likewise, strong left-hemisphere advantages are found in unprimed lexical decision performance (e.g., Leiber, 1976), as well as in unprimed word-naming performance (unpublished observations from my laboratory). However, hemispheric asymmetries are not found in baseline performance in stem completion priming experiments (Marsolek et al., 1992, 1994, 1996). Thus, unlike stem completion priming, the priming measured in perceptual identification, lexical decision, and word naming can be detrimentally affected by differing statistical influences from asymmetric baselines (e.g., see Jernigan & Ostergaard, 1993; Ostergaard, 1994).

The neural subsystems theory posits that an abstract subsystem stores sets of relatively invariant features (see Figure 1) and a specific subsystem stores visually distinctive wholes (see Figure 2). If so, how do they accomplish stem completion (how can “letters be mentally added” to the ends of stems to form words in visual subsystems)? Vector completion from partial vectors to the most similar complete vectors in storage (e.g., see Knapp & Anderson, 1984; McClelland & Rumelhart, 1985), some of which may be primed, should occur in both subsystems. This vector completion process from stems to words would occur over sets of relatively invariant features in one subsystem but over visually distinctive whole representations in the other.

It also should be noted that the main conclusions from this study are not compromised by the facts that (1) the stems of the prime words appeared on roughly the left half of the display during initial encoding, and (2) the beginning letters of stems appeared closer to the fovea in right visual field test presentations than in left. First, participants viewed prime words for 3 s each, and hence eye movements assured that visual information from both sides of the words was projected directly to both hemispheres. Thus, unlike what may be suspected initially, the stems (on the left sides of prime words) were not lateralized during encoding. Second, any advantage/disadvantage during test that may be accrued from certain letters being presented closer to the fovea in one visual field than in the other, or from well-established left-to-right reading habits, should lead to significant visual-field main effects and would not explain the interaction effects involving visual field. For example, distance to the fovea or left-to-right reading habits would not explain why a left visual field advantage was observed in specific priming in some conditions but not others, whereas abstract priming was observed in all conditions following right visual field presentations.

Another aspect of the present data deserves comment. In both Experiments 1 and 2, case-specific priming was observed in strongly significant effects of greater same-case than different-case priming, when dissimilar-case items were presented directly to the right hemisphere. In contrast, an unpredicted difference of greater different-case than same-case priming was observed when dissimilar-case items were presented directly to the left hemisphere (see the left side of Figure 3). This difference was marginally significant or significant in Experiment 1, but it was not significant in Experiment 2. Because the strong same-case advantage in right-hemisphere test presentations replicates many previous experiments (e.g., Burgund & Marsolek, 1997; Koivisto, 1995, 1996; Marsolek & Andresen, 2003; Marsolek & Hudson, 1999; Marsolek et al., 1992, 1994, 1996), but the different-case advantage in left-hemisphere test presentations of the present Experiment 1 has not been observed in any of the other experiments (including the present Experiment 2 and two other experiments conducted in the same manner as that of the present experiments except that the stems were pattern masked; Marsolek & Andresen, 2003), the present conclusion is that the different-case advantage may be justifiably considered spurious.

Comparing different theories, one aspect of strongly abstractionist theories is consistent with the neural subsystems theory, in that one of the neural subsystems does store very abstract visual word representations. However, the existence of case-specific priming in another subsystem (independent of explicit memory) when the stimuli did not encourage access to representations not used in normal word recognition is inconsistent with strongly abstractionist theories. Also, one aspect of exemplar-based theories is consistent with the neural subsystems theory, in that one of the neural subsystems does store specific visual word

representations. However, the existence of abstract priming in a neurally dissociable subsystem is inconsistent with those theories. Because it posits that some visual word representations are abstract and others are specific, the neural subsystems theory may be viewed as a particular theory within the weakly abstractionist approach. However, it differs from other theories that may be considered weakly abstractionist. For example, Brown and Carr (1993) hypothesize that both prototype representations and specific representations exist and contribute to visual word recognition. If the prototype representations are prestored, this theory is in line with the weakly abstractionist approach; if they are constructed on-line as in Hintzman (1986), this theory is in line with the exemplar-based approach. Brown and Carr hypothesize that the typicality of a test word predicts the likelihood of specificity effects in priming; only atypical test items activate the relevant specific representations very effectively. In contrast, according to the neural subsystems theory, the typicality of test stimuli should not strongly influence specificity effects, and this hypothesis was supported in the present study.

To explain visual word recognition more generally, the neural subsystems theory should predict when abstract and specific processing will occur in nonlateralized situations. Recent research suggests important factors. First, task demands appear to be crucial for predicting abstract/specific effects, because different tasks probably influence which subsystem will win any race between the two to guide postvisual processing (see Burgund & Marsolek, 1997; Marsolek & Hudson, 1999). Second, stimulus quality during encoding may be crucial, because visual degradation tends to detrimentally affect an abstract subsystem to a greater degree than a specific subsystem (Marsolek & Hudson, 1999; see also Marsolek, 1999; Marsolek & Burgund, 2003). Third, the novelty of unfamiliar visual forms may be important for predicting specificity effects, because the novelty in unfamiliar visual forms is in their holistic structures, and a specific subsystem should store holistic information effectively (Marsolek et al., 1996). As noted above, Brown and Carr (1993) found that specific priming is more likely to be observed for atypical than for typical test items. If so, why were such typicality effects not observed in the present experiments? One possibility is that Brown and Carr's effects may be observed only when the atypical test items are preexperimentally novel (e.g., handwritten forms, which may not match stored representations precisely in a specific subsystem), and not when they correspond to preexisting representations (e.g., all-uppercase typical-font forms, as in the present study). When the forms are truly novel, a specific subsystem may support priming for the new whole-based form as well as priming for the most similar whole form in storage. This could increase specific priming effect sizes, relative to abstract priming, and underlie the typicality effect observed by Brown and Carr and others.

In contrast, the likelihood of interactions between the hippocampus and visual form subsystems in neocortex, and their involuntary influences on priming effects, are more difficult to predict. Mixed results have been observed in the literature (compare Kinoshita & Wayland, 1993, and Schacter, Church, & Bolton, 1995, against Vaidya, Gabrieli, Verfaellie, Fleischman, & Askari, 1998, and Hamann & Squire, 1997). It may be suggested that unlimited viewing time of test stems accentuates involuntary explicit memory in presumably implicit priming tests, because Curran et al. (1996) used unlimited stem exposures and found greater specificity effects following shallow encoding than following deep encoding. However, caution must be applied, as Curran et al. did not obtain a significant interaction between depth of encoding and same-case/different-case priming (the significant results were in simple effects). Also, there was no test of whether the priming results could be dissociated from

explicit memory. Furthermore, when Graf and Ryan (1990) observed greater specific priming following shallow encoding than following deep encoding, they also observed the same pattern of results in a recognition memory test. Thus, it is unclear whether hippocampal interactions were necessary for the specificity effects. Additional research clearly is needed to determine whether task or stimulus demands (or other variables) influence when hippocampal interactions are likely to contribute to priming effects, especially exemplar-specific priming effects. Similar to the present study, such research may benefit greatly from integrating evidence from multiple levels of analysis to supplement purely behavioural results and constrain functional-level theories.

## REFERENCES

- Beaumont, J. G. (1982). Studies with verbal stimuli. In J. G. Beaumont (Ed.), *Divided visual field studies of cerebral organization* (pp. 57–86). New York: Academic Press.
- Boles, D. B., & Clifford, J. E. (1989). An upper- and lowercase alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments, & Computers*, *21*, 579–583.
- 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.
- Bowers, J. S. (2000). In defense of abstractionist theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, *7*, 83–99.
- Bowers, J. S., & Michita, Y. (1998). An investigation into the structure and acquisition of orthographic knowledge: Evidence from cross-script Kanji-Hiragana priming. *Psychonomic Bulletin & Review*, *5*, 259–264.
- 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.
- Brysbaert, M. (1994). Interhemispheric transfer and the processing of foveally presented stimuli. *Behavioural Brain Research*, *64*, 151–161.
- Buckner, R. L., Petersen, S. E., Ojemann, J. G., Miezin, F. M., Squire, L. R., & Raichle, M. E. (1995). Functional anatomical studies of explicit and implicit memory retrieval tasks. *Journal of Neuroscience*, *15*, 12–29.
- Bunt, A. H., Mickler, D. S., & Johanson, G. W. (1977). Demonstration of bilateral projection of the central retina of the monkey with horseradish peroxidase neuronography. *Journal of Comparative Neurology*, *171*, 619–630.
- Burgund, E. D., & Marsolek, C. J. (1997). Letter-case specific priming in the right cerebral hemisphere with a form-specific perceptual identification task. *Brain and Cognition*, *35*, 239–258.
- Burgund, E. D., Marsolek, C. J., & Luciana, M. (2003). Serotonin levels influence patterns of repetition priming. *Neuropsychology*, *17*, 161–170.
- Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671–684.
- Craik, F. I. M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, *104*, 268–294.
- Curran, T., Schacter, D. L., & Bessenoff, G. (1996). Visual specificity effects in word stem completion: Beyond transfer appropriate processing? *Canadian Journal of Experimental Psychology*, *50*, 22–33.
- Dimond, S. J., Gibson, A. R., & Gazzaniga, M. S. (1972). Cross field and within field integration of visual information. *Neuropsychologia*, *10*, 379–381.
- Feustel, T. C., Shiffrin, R. M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General*, *112*, 309–346.
- Forster, K., Booker, J., Schacter, D. L., & Davis, C. (1990). Masked repetition priming: Lexical activation or novel memory trace? *Bulletin of the Psychonomic Society*, *28*, 341–345.
- Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton Mifflin.
- Graf, P., & Ryan, L. (1990). Transfer-appropriate processing for implicit and explicit memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 978–992.

- Graf, P., Shimamura, A. P., & Squire, L. R. (1985). Priming across modalities and priming across category levels: Extending the domain of preserved function in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*, 385–395.
- Gross, C. G., Rocha-Miranda, C. E., & Bender, D. B. (1972). Visual properties of neurons in inferotemporal cortex of the macaque. *Journal of Neurophysiology*, *35*, 96–111.
- Hamann, S. B., & Squire, L. R. (1997). Intact priming for novel perceptual representations in amnesia. *Journal of Cognitive Neuroscience*, *9*, 699–713.
- Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA: Harvard University Press.
- Hintzman, D. L. (1986). "Schema abstraction" in a multiple-trace memory model. *Psychological Review*, *93*, 411–428.
- Hyde, T. S., & Jenkins, J. J. (1973). Recall for words as a function of semantic, graphic, and syntactic orienting tasks. *Journal of Verbal Learning and Verbal Behavior*, *12*, 471–480.
- Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General*, *110*, 306–340.
- Jacoby, L. L., & Hayman, C. A. G. (1987). Specific visual transfer in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 456–463.
- Jacoby, L. L., Levy, B. A., & Steinbach, K. (1992). Episodic transfer and automaticity: Integration of data-driven and conceptually-driven processing in rereading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 15–24.
- Jernigan, T. L., & Ostergaard, A. L. (1993). Word priming and recognition memory both affected by mesial temporal lobe damage. *Neuropsychology*, *7*, 14–26.
- Jordan, T. R., Patching, G. R., & Milner, A. D. (1998). Central fixations are inadequately controlled by instructions alone: Implications for studying cerebral asymmetry. *Quarterly Journal of Experimental Psychology*, *51A*, 371–391.
- Kinoshita, S., & Wayland, S. V. (1993). Effects of surface features on word-fragment completion in amnesic subjects. *American Journal of Psychology*, *106*, 67–80.
- Kirsner, K. (1973). An analysis of the visual component in recognition memory for verbal stimuli. *Memory & Cognition*, *1*, 449–453.
- Kirsner, K., & Smith, M. C. (1974). Modality effects in word identification. *Memory & Cognition*, *2*, 637–640.
- Knapp, A., & Anderson, J. A. (1984). A signal averaging model for concept formation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 616–637.
- Koivisto, M. (1995). On functional brain asymmetries in perceptual priming. *Brain and Cognition*, *29*, 36–53.
- Koivisto, M. (1996). Form-specific priming and functional brain asymmetries in perceptual identification. *Cortex*, *32*, 527–536.
- Kolers, P. A. (1973). Remembering operations. *Memory & Cognition*, *1*, 347–355.
- Kolers, P. A. (1975). Specificity of operations in sentence recognition. *Cognitive Psychology*, *1*, 283–306.
- Leiber, L. (1976). Lexical decisions in the left and right cerebral hemispheres. *Brain and Language*, *3*, 443–450.
- Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology*, *22*, 1–35.
- Logothetis, N. K., & Sheinberg, D. L. (1996). Visual object recognition. *Annual Review of Neuroscience*, *19*, 577–621.
- Marsolek, C. J. (1995). Abstract-visual-form representations in the left cerebral hemisphere. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 375–386.
- Marsolek, C. J. (1999). Dissociable neural subsystems underlie abstract and specific object recognition. *Psychological Science*, *10*, 111–118.
- Marsolek, C. J. (2003). What is priming and why? In J. S. Bowers & C. J. Marsolek (Eds.), *Rethinking implicit memory* (pp. 41–64). Oxford, UK: Oxford University Press.
- Marsolek, C. J., & Andresen, D. R. (2003). *Interactive visual and postvisual subsystems and their roles in form-specific memory*. Manuscript submitted for publication.
- Marsolek, C. J., & Burgund, E. D. (1997). Computational analyses and hemispheric asymmetries in visual-form recognition. In S. Christman (Ed.), *Cerebral asymmetries in sensory and perceptual processing* (pp. 125–158). Amsterdam: Elsevier.
- Marsolek, C. J., & Burgund, E. D. (2003). Visual recognition and priming of incomplete objects: The influence of stimulus and task demands. In J. S. Bowers & C. J. Marsolek (Eds.), *Rethinking implicit memory* (pp. 139–156). Oxford, UK: Oxford University Press.

- Marsolek, C. J., & Hudson, T. E. (1999). Task and stimulus demands influence letter-case specific priming in the right cerebral hemisphere. *Laterality, 4*, 127–147.
- 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.
- Marsolek, C. J., Nicholas, C. D., & Andresen, D. R. (2002). Interhemispheric communication of abstract and specific visual-form information. *Neuropsychologia, 40*, 1983–1999.
- Marsolek, C. J., Schacter, D. L., & Nicholas, C. D. (1996). Form-specific visual priming for new associations in the right cerebral hemisphere. *Memory & Cognition, 24*, 539–556.
- Marsolek, C. J., Squire, L. R., Kosslyn, S. M., & Lulenski, M. E. (1994). Form-specific explicit and implicit memory in the right cerebral hemisphere. *Neuropsychology, 8*, 588–597.
- Masson, M. E. J. (1986). Identification of typographically transformed words: Instance-based acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*, 479–488.
- McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review, 102*, 419–457.
- McClelland, J. L., & Rumelhart, D. E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General, 114*, 159–188.
- Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85*, 207–238.
- Mishkin, M., & Forgy, D. G. (1952). Word recognition as a function of retinal locus. *Journal of Experimental Psychology, 43*, 43–48.
- Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen models. In P. A. Kollers, M. E. Wrolstad, & H. Bouma (Eds.), *Processing of visible language* (Vol. 1, pp. 259–268). New York: Plenum Press.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.
- O'Reilly, R. C., & McClelland, J. L. (1994). Hippocampal conjunctive encoding, storage, and recall: Avoiding a trade-off. *Hippocampus, 4*, 661–682.
- Ostergaard, A. L. (1994). Dissociations between word priming effects in normal subjects and patients with memory disorders: Multiple memory systems or retrieval? *Quarterly Journal of Experimental Psychology, 47A*, 331–364.
- Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology, 36*, 475–543.
- Richardson-Klavehn, A., Gardiner, J. M., & Java, R. I. (1994). Involuntary conscious memory and the method of opposition. *Memory, 2*, 1–29.
- Roediger, H. L. (1990). Implicit memory: Retention without remembering. *American Psychologist, 45*, 1043–1056.
- Roediger, H. L., III, & Blaxton, T. A. (1987). Retrieval modes produce dissociations in memory for surface information. In D. S. Gorfein & R. R. Hoffman (Eds.), *Memory and cognitive processes: The Ebbinghaus centennial conference* (pp. 349–379). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Ryan, L., Ostergaard, A., Norton, L., & Johnson, J. (2001). Search and selection processes in implicit and explicit word-stem completion performance in young, middle-aged, and older adults. *Memory & Cognition, 29*, 678–690.
- Scarborough, D. L., Cortese, C., & Scarborough, H. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1–17.
- Schacter, D. L. (1994). Priming and multiple memory systems: Perceptual mechanisms of implicit memory. In D. L. Schacter & E. Tulving (Eds.), *Memory systems 1994* (pp. 233–268). Cambridge, MA: MIT Press.
- Schacter, D. L., Church, B. A., & Bolton, E. (1995). Implicit memory in amnesic patients: Impairment of voice-specific priming. *Psychological Science, 6*, 20–25.
- Springer, S. P., & Deutsch, G. (1998). *Left brain, right brain: Perspectives from cognitive neuroscience* (5th ed.). New York: Freeman.
- Squire, L. R. (1992). Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. *Psychological Review, 99*, 195–231.
- Tenpenny, P. L. (1995). Abstractionist versus episodic theories of repetition priming and word identification. *Psychonomic Bulletin & Review, 2*, 339–363.
- Tootell, R. B. H., Mendola, J. D., Hadjikhani, N. K., Liu, A. K., & Dale, A. M. (1998). The representation of the ipsilateral visual field in human cerebral cortex. *Proceedings of the National Academy of Sciences USA, 95*, 818–824.

- Vaidya, C. J., Gabrieli, J. D. E., Verfaellie, M., Fleischman, D., & Askari, N. (1998). Font-specific priming following global amnesia and occipital lobe damage. *Neuropsychology, 12*, 183–192.
- Webster's Vest Pocket Dictionary*. (1989). Springfield, MA: Merriam-Webster.
- Young, A. W., Ellis, A. W., & Bion, P. J. (1984). Left hemisphere superiority for pronounceable nonwords, but not for unpronounceable letter strings. *Brain and Language, 22*, 14–25.

*Original manuscript received 2 April 2002*  
*Accepted revision received 25 July 2003*  
*PrEview proof published online 22 January 2004*

