

# **Task and Stimulus Demands Influence Letter-case–Specific Priming in the Right Cerebral Hemisphere**

Chad J. Marsolek

*University of Minnesota, USA*

Todd E. Hudson

*Columbia University, USA*

A greater tendency to complete single-completion word stems (e.g. “BEY”) to form previously read whole words (e.g. “BEYOND”) was found when test stems were presented in the same letter case as their previously encoded words, compared with the different letter case, but only when stems were presented directly to the right hemisphere (i.e. in the left visual field) and not when they were presented directly to the left hemisphere (i.e. in the right visual field). This finding with single-completion stems was robust (i.e. observed for both lowercase and uppercase stems) when the initial encoding task was perceptually demanding, but it was test-case dependent (i.e. observed for uppercase but not lowercase stems) when the initial encoding task was not perceptually demanding. Results and theory help to explain why letter-case-specific priming in right-hemisphere test presentations is typically test-case dependent when priming is measured using perceptual identification at test, but is consistently robust when priming is measured using multiple-completion word stems (e.g. “BEA”) at test. Demands from both the stimuli and tasks affect the relative contributions of abstract and specific subsystems to the processing of visual forms.

---

Requests for reprints should be sent to C.J. Marsolek, Department of Psychology, University of Minnesota, 75 East River Road, Minneapolis, MN 55455, USA. Email: chad.j.marsolek-1@umn.edu  
WWW: <http://levels.psych.umn.edu>

This research was supported by the US National Institute of Mental Health, Grant MH53959-01; 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.

We wish to thank Chris Azorson for substantial discussion, Darcy Burgund for valuable comments on an earlier draft of this article, and Jeff Johnston for assistance with data collection and analysis. An earlier report of this research was presented at the Annual Meeting of the Cognitive Neuroscience Society, Boston, 1997.

## INTRODUCTION

Attempts have been made in the past to explain functional hemispheric asymmetries by theorising that whole abilities or tasks are lateralised. However, such asymmetries may be more effectively explained by hypothesising that relatively independent neural processing subsystems perform separable component functions and operate more or less effectively in different hemispheres (Hellige, 1993; see also Gazzaniga, 1989; Kosslyn, 1987; Posner & McCandliss, 1993). A critical aspect of theorising within this separate-subsystems approach is to analyse the demands placed on different subsystems by the tasks that are used in different experimental conditions. In memory paradigms, the demands of the encoding task must be considered in order to hypothesise which subsystems are likely to subservise the structural changes that store information. Likewise, the demands of the test task must be considered in order to hypothesise whether the subsystems that contain stored information are also among those that are needed to accomplish the test task. Presumably, memory effects may be produced when the subsystems that contain stored information are among those that are accessed to perform the test task, and not otherwise. In this article, we consider such task analyses to attempt to explain an empirical discrepancy in the visual priming literature. The results from two experiments help to resolve the previous discrepancy.

Recent evidence suggests that hemispheric asymmetries in visual-form recognition are produced by relatively independent subsystems that underlie abstract versus specific recognition (for an empirical review and computational theory, see Marsolek & Burgund, 1997). On the one hand, an *abstract visual-form subsystem* underlies recognition of abstract categories of shape. For example, despite their visual dissimilarities, “bear” and “BEAR” activate the same abstract representation; a representation that nonetheless stores visual information *per se* (Bowers, 1996; Marsolek, 1995). Presumably, feedback from post-visual subsystems, indicating that the two forms are associated with common phonological and semantic information, enables this subsystem to learn that the two shapes should be categorised together. Likewise, “gang” and “GANG” belong to another abstract category. An abstract visual-form subsystem produces output that indicates the abstract category of an input form.

On the other hand, a *specific visual-form subsystem* underlies recognition of specific exemplars. For example, “bear”, “BEAR”, “gang”, and “GANG” are all different exemplars of shape, and we typically learn to differentiate such exemplars. A specific visual-form subsystem produces output that indicates the specific exemplar of an input form. Previous results indicate that an abstract visual-form subsystem operates more effectively than a specific visual-form subsystem in the left cerebral hemisphere, whereas a specific visual-form subsystem operates more effectively than an abstract visual-form subsystem in the right cerebral hemisphere (Marsolek, 1995). Some of the evidence in support

of this theory comes from asymmetries in word-stem completion priming experiments (Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996; Marsolek, Squire, Kosslyn, & Lulenski, 1994). However, a recent study of priming in a perceptual identification experiment (Koivisto, 1996; see also Koivisto, 1995) produced a different pattern of results and only equivocal evidence in support of the separate subsystems theory.

## Empirical Discrepancy Across Priming Tasks

In several previous studies, participants completed word stems (each of which could have been completed to form at least 10 common English words; e.g. "BEA") using the first word that came to mind per stem. Unannounced to the participants, half of the stems could be completed to form words that had been read previously during an encoding task, and of these, half were presented in the same letter case, and half in the different letter case, compared with their corresponding whole words. Repetition priming was measured as a greater tendency to complete stems using critical word completions when those critical words had been read previously than when they had not been processed earlier in the experiment. In addition, letter-case-specific priming was measured as a greater tendency to complete stems to form critical words primed in the same letter case than those primed in the different letter case. Most important, letter-case-specific priming was observed when stems were presented directly to the right hemisphere (briefly in the left visual field) during test, but no letter-case-specific priming was observed when stems were presented directly to the left hemisphere (briefly in the right visual field) during test. It is important to emphasise that this pattern of results was obtained both when lowercase stems (e.g. "bea") were presented at test and when uppercase stems (e.g. "BEA") were presented at test, hence the finding was *test-case independent*. These results indicate that the sort of priming hypothesised for a specific visual-form subsystem (letter-case specific) is observed when right-hemisphere subsystems are advantaged by the stimulus input at test, and the sort of priming hypothesised for an abstract visual-form subsystem (letter-case abstract; i.e. no difference between same-case and different-case primed performance) is observed when left-hemisphere subsystems are advantaged at test, consistent with the separate subsystems theory (Marsolek et al., 1992, 1994, 1996).

Contrastingly, in a perceptual identification study, participants identified and reported briefly presented whole words. Unannounced to the participants, half of the words had been read previously during an encoding task, and of these, half were presented in the same letter case, and half in the different letter case, compared with encoding. Letter-case-specific priming was measured as a greater tendency to identify words primed in the same letter case than those primed in the different letter case. Most important, letter-case-specific priming was observed when words were presented directly to the right hemisphere during test and not

when words were presented directly to the left hemisphere during test, but only when uppercase test words were presented. When lowercase test words were presented, there was no greater letter-case-specific priming in right-hemisphere than in left-hemisphere test presentations. Hence, the important interaction effect was *test-case dependent* in this experiment, providing only equivocal evidence for the separate subsystems hypothesis (Koivisto, 1996; see also Koivisto, 1995).

The main question addressed in the present study concerns the discrepancy in results between priming measured in word-stem-completion studies and priming measured in a perceptual identification study. Why is the hemispheric asymmetry in case-specific priming robust (does *not* differ depending on the letter case of the test items) in several studies of word-stem-completion priming, but not robust (differs depending on the letter case of the test items) in a study of perceptual identification priming?

### Differing Task Demands Across Priming Tests

One possible reason for the discrepant results relies on the idea that the requirements for the stem-completion and perceptual-identification tasks place qualitatively different demands on the underlying neural subsystems. In the word-stem-completion task, a portion of a word is presented in each trial, and the participant must generate a word that completes the stem. The participant is only weakly constrained by the stimulus, in that *many* correct responses (at least 10 common words; Marsolek et al., 1992, 1994, 1996) can be produced per test item. The weakly constrained nature of the task may have the effect that a number of diverse subsystems, especially including a specific visual-form subsystem, are able to contribute substantially to completion performance. In fact, various forms of priming have been observed in stem completion, including both case-specific and case-abstract priming (Marsolek et al., 1992, 1994, 1996), auditory-to-visual cross-modality priming (Graf, Shimamura, & Squire, 1985; Marsolek et al., 1992; Rajaram & Roediger, 1993), as well as semantic priming (Keane et al., 1991). The important consequence is that a specific visual-form subsystem may contribute as much to the observed priming effects as an abstract visual-form subsystem, when multiple-completion word stems are presented at test. This may help to explain why case-specific priming is robust with this task; a specific subsystem is on equal footing with other subsystems, allowing it to contribute substantially to processing and produce case-specific priming effects for both lowercase and uppercase test stems.

However, in the perceptual identification task, a complete word is presented in each trial, and the participant must identify and report that word. The participant is more strongly constrained by the stimulus, in that only one correct response should be produced per test stimulus. The strongly constrained nature of the task may have the effect that the most efficient subsystem is recruited very frequently to accomplish the task. Given that the demands of the task are to

report the word without regard to whether it is presented in lowercase or uppercase letters, an abstract visual-form subsystem may be most efficient, as it effectively ignores letter case information in order to recognise abstract categories. In fact, when perceptual identification is used, only small and inconsistent case-specific priming is observed (Bowers, 1996; Clarke & Morton, 1983; Feustel, Shiffrin, & Salasoo, 1983; Jacoby & Hayman, 1987; Rajaram & Roediger, 1993), even though this priming is supported in large part by visual subsystems (e.g. it is significantly reduced when words are presented auditorily during initial encoding; Bowers, 1996, Clarke & Morton, 1983; Jacoby & Dallas, 1981; Keane et al., 1991; Kirsner, Milech, & Standen, 1983; Rajaram & Roediger, 1993). Thus, the important consequence is that a specific visual-form subsystem may *not* contribute as much as an abstract visual-form subsystem to the priming obtained in the perceptual identification task. This may help to explain why case-specific priming is not robust when perceptual identification is used. Case-specific priming in this task may be limited to trials in which uppercase words are presented at test, because uppercase test words have visual structures that are more novel than those of lowercase test words, and a specific visual-form subsystem is especially effective at encoding and storing novel visual form information (Marsolek et al., 1996). Thus, a specific subsystem may be able to overcome its usual disadvantage in this task only when the test stimuli contain the sort of information stored most effectively in this subsystem.

Using similar reasoning, Burgund and Marsolek (1997) found that changing the demands of the standard perceptual identification task so that they required contributions from a specific subsystem (participants were required to print each identified test item in the same letter case in which that item appeared) created a situation in which the observed priming effects were similar to those from stem-completion studies. However, it is still unclear why the hemispheric asymmetry in case-specific priming is robust with respect to test case in stem completion but not in standard perceptual identification. In the following experiment, we changed the demands of the stem-completion task so that they were more like those of the standard perceptual identification task. In particular, we used word stems that could be completed to form only one common English word (e.g. ‘‘BEY’’ for ‘‘BEYOND’’), so that, as in standard perceptual identification, only one correct response could be produced per test stimulus, even though the task was stem completion. In this way, we examined whether the *demands* of the test task (strongly versus weakly constrained by the stimuli) or the test task *per se* (stem completion versus standard perceptual identification) predicts robust hemispheric asymmetries in case-specific priming.

## EXPERIMENT 1

In this experiment, participants read a list of words aloud during the initial encoding task. Words were presented one at a time for three seconds each in the

central visual field. Half of the words were presented in all lowercase letters, and half were presented in all uppercase letters. Afterwards, participants completed three-letter word stems to form word completions during the test task. Single-completion stems were presented one at a time, briefly in the left or right visual field, giving subsystems in one hemisphere initiation-time and stimulus-quality advantages in processing the stems over subsystems in the other hemisphere (e.g. Gross, Rocha-Miranda, & Bender, 1972). Half of the stems could be completed to form words that had been read previously in the same letter case, and the other half could be completed to form words primed in the different letter case. If the demands of the test task predict hemispheric asymmetries for case-specific priming, and if single-completion stems strongly constrain correct responses in this task, then case-specific priming should be obtained in right-hemisphere but not left-hemisphere test presentations, but only for uppercase test items (as in a previous perceptual identification experiment; Koivisto, 1996). In contrast, if the test task *per se* predicts hemispheric asymmetries for case-specific priming, then the results in this stem-completion experiment should indicate case-specific priming in right-hemisphere but not left-hemisphere test presentations, for both lowercase and uppercase test items (as in previous stem-completion studies with multiple-completion stems; Marsolek et al., 1992, 1994, 1996).

## Method

*Participants.* A total of 32 (16 female and 16 male) University of Arizona undergraduates volunteered for course credit. All participants were right-handed (mean laterality quotient = .85, range = .41–1.0, as measured through the Edinburgh Handedness Inventory; Oldfield, 1971), and were native English speakers.

*Design.* A  $2 \times 2 \times 2 \times 2$  mixed design was used. Type of initial encoding (same case vs. different case), hemisphere of direct test presentation (left vs. right), and letter case of test presentation (lowercase vs. uppercase) were manipulated as within-participant factors, and sex of participants (female vs. male) was a between-participants factor.

*Materials.* A total of 23 English words and their corresponding three-letter word stems were used in the experiment; 16 of them were presented both at encoding (as whole words) and at test (as word stems)—these were the experimental items. Of the remaining seven words, five were used as buffer items during encoding (three at the beginning and two at the end, to attenuate primacy and recency effects, respectively), and the stems of the other two words were used as practice stem-completion items, which were presented at the beginning of each test block.

The 16 critical words were: also, always, beyond, duty, each, five, jazz, kick, lake, often, rule, rural, system, take, upon, wife (mean of 418 occurrences per million; Francis & Kucera, 1982). They were chosen with the constraint that their first three letters could be completed to form only that one word of all the words found in *Webster's Vest Pocket Dictionary* (1989). This constraint restricted the number of potential experimental items, which is why a small number (16) was used. The other 7 words were chosen from the same source and had the same characteristics as the 16 critical words.

The critical words were divided into four sublists of four words each for counterbalancing purposes. These sublists were balanced for word frequency and for the tendency to complete the stems correctly when their word completions had not been primed (assessed with 11 pilot participants). Sublists were rotated through the experimental conditions across participants, such that each sublist (and hence each item) represented each of the conditions an equal number of times across participants.

The stimuli were presented on an AppleColor High Resolution RGB Monitor with a Polaroid CP-50 Filter placed over it for glare reduction. Stimulus presentation was controlled by a Macintosh II computer. Letters were presented in black against a white background in a 24-point bold Helvetica font. All stimuli were preceded by a fixation dot (subtending  $0.23^\circ$  of visual angle) presented in the centre of the display. Whole words were presented centrally during initial encoding, and word stems were presented laterally at test such that the centre of each three-letter string was  $2.6^\circ$  from the centre of the display, and the inner edge was never less than  $1.5^\circ$  from the centre of the display. Participants' head positions were stabilised with a chinrest so that their eyes were approximately 50cm from the monitor.

*Procedure.* Each participant was tested individually in a session composed of an encoding phase and a test phase.

During the encoding phase, participants spoke aloud the names of whole words presented on the computer display. For each participant, the list of 16 critical words (half in all lowercase letters and the other half in all uppercase letters) was processed twice in succession, with both passes occurring between the three beginning and two ending filler trials. Thus, there were 37 encoding trials per participant. Different pseudo-random orders were used across the two passes per participant and across participants. These orders were random with the constraints that no more than three words were presented consecutively that would appear (a) in the same or different letter case at test, (b) in the left or right visual field at test, or (c) in uppercase or lowercase letters during encoding.

The sequence of events for each encoding trial was as follows. Each trial began with an instruction to press the space bar. After the space bar was pressed, a blank screen was presented for 500 milliseconds, and then the fixation dot

appeared in the centre of the display for 500 milliseconds. Participants were asked to stare at the fixation dot the entire time that it appeared on the display. Immediately after the fixation dot disappeared, a word appeared for three seconds in the centre of the display. Participants were instructed to speak aloud the word as quickly as possible after it disappeared, in order to ensure that participants attended to the word for the full three seconds. An experimenter recorded the spoken responses. After each response, an auditory recording of the correct name was played, so that participants could verify the correct name for the word presented (this verification was more important for the brief presentations in Experiment 2, but to keep the procedures similar across experiments, feedback was presented in this experiment as well). There was a one-second interval between trials.

During the test phase, participants completed word stems and spoke aloud the names of their word completions. The test phase was composed of two blocks of trials. The first block began approximately four minutes after the encoding phase ended, and the second block began approximately four minutes after the first block.

In the first test block, the stems of the 16 critical words were presented once in all lowercase letters and once in all uppercase letters (with the lowercase version of any one stem presented in one visual field and the uppercase version of that stem presented in the other visual field). Sixteen of the stems (eight in the left visual field [four of these in all lowercase letters and the other four in all uppercase letters] and eight in the right visual field [four of these in all lowercase letters and the other four in all uppercase letters]) could be completed to form words that had been read during encoding in the same letter case as their corresponding stems. The other sixteen of the stems (again, eight in the left visual field [four of these in all lowercase letters and the other four in all uppercase letters] and eight in the right visual field [four of these in all lowercase letters and the other four in all uppercase letters]) could be completed to form words that had been read during encoding in the different letter case compared with their corresponding stems. In the second test block, the items from the first block were presented again, in the same manner as in the first block, except that all items that were presented in the left visual field during the first block were presented in the right visual field, and all items that were presented in the right visual field during the first block were presented in the left visual field. In addition, two practice stem-completion trials (involving unprimed word stems—one in all lowercase letters and the other in all uppercase letters) were completed before the 32 critical trials in each block, in order to familiarise the participants with the test procedure before the critical trials began. Thus, there were 34 trials per test block for each participant. Different pseudo-random orders were used across the two test blocks per participant and across participants. These orders were random with the constraints that no more than three stems were presented consecutively that

were (a) in the same letter case, (b) in the same visual field, or (c) in the same or different letter case compared with encoding.

The sequence of events for each trial was as follows. Each trial began with the instruction to press the space bar. After the space bar was pressed, a blank screen was presented for 500 milliseconds, and then the fixation dot appeared in the centre of the display for 500 milliseconds. Participants were asked to stare at the fixation dot the entire time that it appeared on the display. Immediately after the fixation point disappeared, a three-letter word stem appeared in a position to the left or right of the centre of the display for 183 milliseconds, quickly enough that attention-based saccades could not be used to foveate the items. Participants were instructed to complete each stem with the first word that came to mind and to speak aloud each word completion as soon as they had thought of it. An experimenter recorded the spoken responses. After each response, an auditory recording of the correct response for that trial was played so that participants could verify whether their response was correct. There was a one-second interval between trials.

In summary, for each participant, 16 same-case stems (8 in all lowercase letters and 8 in all uppercase letters) were presented in the left visual field, 16 same-case stems (8 in all lowercase letters and 8 in all uppercase letters) were presented in the right visual field, 16 different-case stems (8 in all lowercase letters and 8 in all uppercase letters) were presented in the left visual field, and 16 different-case stems (8 in all lowercase letters and 8 in all uppercase letters) were presented in the right visual field. Counterbalancing assured that, across participants, each stimulus represented each experimental condition an equal number of times.

## Results

We scored each stem-completion response as correct only if it exactly matched the critical word associated with the stem presented in that trial. Thus, no plurals, past tense forms, or other changes from the original critical words were accepted. In one repeated-measures analysis of variance, stem-completion accuracy was the dependent measure ( $F_1$ ). Because the accuracy rates were consistently very high, we also conducted a repeated-measures analysis of variance ( $F_2$ ) with arcsine-transformed accuracy rates as the dependent measure (following recommendations in Howell, 1987). The arcsine transform helps to normalise proportion data, and is especially useful for helping to normalise samples of proportions in which the mean departs widely from .5 (Johnson, 1949). When means of proportions approach 0 and 1, variances approach 0 (e.g. a mean of 0 will always require a sample of all 0s). The arcsine transform is particularly useful because, as the mean proportion ranges from 0 to 1, the output of the transform varies from 0 to 3.14 (in the case of the transform recommended in Howell, 1987), but the function is positively accelerated from

.5 to 1 (and negatively accelerated from .5 to 0). This causes an expansion in the tails, helping to overcome any artificial suppression of variances due to the ceiling or floor. Note, however, that the accuracy rates reported in the text and in the figures are the untransformed rates.

In both analyses, type of initial encoding (same case vs. different case), hemisphere of direct test presentation (left vs. right), and letter case of test stems (lowercase vs. uppercase) were within-participant independent variables. Also, in both analyses, the level of significance was set at  $P < .05$ . (Two additional repeated-measures analyses of variance were conducted, one for each dependent measure, with sex of participant as an additional between-participants independent variable, but no main effect of sex nor any interaction with sex approached significance in either analysis.)

Figure 1 displays the main results from this experiment. The most important result was that same-case stems were not more likely to be completed accurately than different-case stems when items were presented directly to the right hemisphere (95.9% versus 95.9%) than when they were presented directly to the left hemisphere (96.9% versus 97.9%),  $F_1 < 1$ ,  $F_2 < 1$ , for the interaction between type of encoding and test hemisphere. However, this pattern of interaction was more evident when uppercase stems were presented at test than when lowercase stems were presented at test,  $F_1(1,31) = 6.09$ ,  $P < .05$ ,  $F_2(1,31) = 5.40$ ,  $P < .05$ , for the three-way interaction between type of encoding, test hemisphere, and

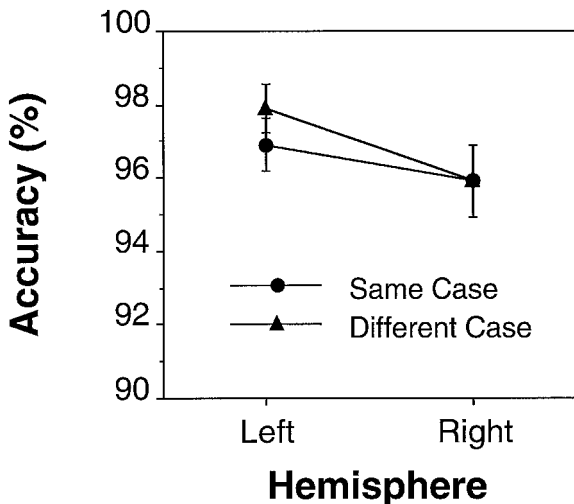


FIG. 1. Results from Experiment 1, in which participants completed single-completion word stems during test after viewing whole prime words for three seconds each during initial encoding. Percentage of accurate word-stem completion is displayed as a function of hemisphere of direct stem presentations and type of initial encoding of corresponding prime words. Error bars indicate standard errors of the mean.

letter case of test stems. Interaction contrasts indicated that, when uppercase stems were presented at test, same-case stems were more likely to be completed accurately than different-case stems when items were presented directly to the right hemisphere (97.3% versus 95.3%) than when they were presented directly to the left hemisphere (96.5% versus 98.8%) in an effect that approached significance in one analysis,  $F_1(1,62) = 3.66$ ,  $P < .06$ , but was significant in the other analysis,  $F_2(1,62) = 4.08$ ,  $P < .05$ , for the interaction contrast. However, when lowercase stems were presented at test, same-case stems were not more likely to be completed accurately than different-case stems when items were presented directly to the right hemisphere (94.5% versus 96.5%) than when they were presented directly to the left hemisphere (97.3% versus 96.9%),  $F_1(1,62) = 1.09$ ,  $P > .30$ ,  $F_2 < 1$ , for the interaction contrast.

In addition, stems presented directly to the left hemisphere were completed more accurately (97.4%) than stems presented directly to the right hemisphere (95.9%) in the first analysis,  $F_1(1,31) = 4.19$ ,  $P < .05$ , although not in the other analysis,  $F_2(1,31) = 2.87$ ,  $P > .10$ , for the main effect of test hemisphere. No other effects approached significance in these analyses (all other  $P$ s  $> .30$ ).

Finally, we conducted additional analyses to test the possibility that the important pattern of results was due to our having to repeat presentations of the same stems across blocks during the test phase (note, however, that each item was presented directly to different hemispheres across test blocks). We analysed the results from the first test block alone, and we found the same pattern of results as in the previous analyses (including both test blocks). Most important, the two-way interaction between type of encoding and test hemisphere was not significant,  $F_1 < 1$ ,  $F_2 < 1$ , but the three-way interaction between type of encoding, test hemisphere, and letter case of test stems was significant,  $F_1(1,31) = 6.20$ ,  $P < .05$ ,  $F_2(1,31) = 6.78$ ,  $P < .05$ . Thus, repetition of test stems across test blocks apparently was not responsible for the important pattern of results.

## Discussion

The most important finding in this experiment was that, collapsing across lowercase and uppercase test items, case-specific priming was not greater when test stems were presented directly to the right hemisphere than when they were presented directly to the left hemisphere. This was true in analyses of both untransformed and transformed data. This pattern of results, obtained with single-completion stems, differs from the pattern obtained in previous stem-completion studies using multiple-completion stems (Marsolek et al., 1992, 1994, 1996), yet it is similar to the pattern obtained in a previous word-identification experiment (Koivisto, 1996). In addition, case-specific priming was greater when test stems were presented directly to the right hemisphere than to the left, but only for stems presented in uppercase letters at test and not for

stems presented in lowercase letters at test. This pattern of results also differs from the pattern obtained in previous stem-completion studies using multiple-completion stems (Marsolek et al., 1992, 1994, 1996), yet it is similar to the pattern obtained in a previous word-identification experiment (Koivisto, 1996). Therefore, the results from Experiment 1 refute the hypothesis that the discrepant priming results between previous studies of stem completion and standard perceptual identification are due to the test tasks *per se*. Rather, the discrepant findings appear to be due to how strongly responses are constrained by the task and stimuli. Thus, the demands of the test task appear to predict the pattern of hemispheric asymmetries (or lack thereof) for case-specific priming.

It may be important to note another conclusion that follows from the comparison between studies. The similarities in results from Experiment 1 and those from the standard perceptual identification experiment (Koivisto, 1996) suggest that the other methodological differences between the two (e.g. language used, proportion of female/male participants, etc.), in addition to the different test tasks *per se*, may not be crucial for understanding any discrepant priming results obtained between stem-completion and standard perceptual-identification tasks.

This experiment produced results similar to those from an identification experiment in part because an abstract visual-form subsystem presumably dominated the processing during test, as hypothesised in the Introduction. Indeed, stems presented in the same letter case as their previously presented prime words generally were *not* completed more accurately than stems primed by words in the different letter case, assessed by a main effect. This finding would be expected if an abstract visual-form subsystem dominated processing in the experiment, because this subsystem should not support case-specific priming. If so, under what circumstances may a specific visual-form subsystem be more likely to contribute significantly to processing in a single-completion stem experiment? We addressed this question in Experiment 2.

## Perceptual Demands During Encoding

Appropriate analyses of task demands should probably not be restricted to test tasks in priming studies. Consider the perceptual demands of the *encoding* task used in Experiment 1. The task was to read aloud a list of words presented one at a time, and each word was presented for three seconds. In this situation, it was very easy to identify each word, and very little perceptual effort should have been required to accomplish the task. In contrast, consider the perceptual demands that would ensue if, instead, each word were presented briefly (e.g. for half a second). In this case, it would be at least slightly more difficult to identify each word, and relatively more perceptual effort would be needed to compensate for the briefly presented visual input. Relatively brief presentations of words during encoding may create a situation in which a specific visual-form

subsystem contributes to processing to a greater degree than it would with longer presentations of words during encoding. This subsystem may be especially important for processing visual inputs in a way that compensates for the visual "degradation" of rapidly disappearing inputs. Indeed, right-hemisphere advantages typically are obtained in visual recognition tasks when stimuli are perceptually degraded (e.g. Hellige, 1976, 1980; Moscovitch, 1983; for reviews, see Christman, 1989; Sergent & Hellige, 1986). Apparently, subsystems that operate effectively in the right hemisphere (e.g. a specific visual-form subsystem) are not disrupted by impoverished visual input as much as subsystems that operate effectively in the left hemisphere (e.g. an abstract visual-form subsystem). Thus, to test whether the perceptual demands (or lack thereof) during the encoding task resulted in little contribution from a specific visual-form subsystem in Experiment 1, we examined priming following brief presentations of prime words in Experiment 2.

## EXPERIMENT 2

This experiment was conducted in the same manner as Experiment 1, except that each word was presented for half a second instead of three seconds during the initial encoding task. If relatively brief visual inputs during encoding result in greater specific visual-form processing in this experiment than in Experiment 1, and if the priming observed with single-completion stems is capable of producing robust evidence that a specific visual-form subsystem operates effectively in the right hemisphere, then the following prediction would be made: Case-specific priming in right-hemisphere, but not left-hemisphere, test presentations should be obtained in an effect that does not depend on whether stems are presented in lowercase or uppercase letters.

### Method

*Participants.* A total of 32 (16 female and 16 male) University of Arizona undergraduates volunteered for course credit. None had participated in Experiment 1. All participants were right-handed (mean laterality quotient = .84, range = .33–1.0, as measured through the Edinburgh Handedness Inventory; Oldfield, 1971), and were native English speakers.

*Design, Materials, and Procedure.* Experiment 2 was conducted in the same manner as Experiment 1, except that each word presented during the encoding phase was displayed for 500 milliseconds rather than three seconds.

### Results

We scored each stem-completion response in the same manner as in Experiment 1, and we conducted analyses in the same manner as in Experiment 1. In

particular, in one repeated-measures analysis of variance, stem-completion accuracy was the dependent measure ( $F_1$ ), and in another, arcsine-transformed accuracy rate was the dependent measure ( $F_2$ ). In both analyses, type of initial encoding (same case vs. different case), hemisphere of direct test presentation (left vs. right), and letter case of test stems (lowercase vs. uppercase) were within-participant independent variables. Also, in both analyses, the level of significance was set at  $P < .05$ . (Two additional repeated-measures analyses of variance were conducted, one for each dependent measure, with sex of participant as an additional between-participants independent variable, but no main effect of sex nor any interaction with sex approached significance in either analysis.)

Figure 2 displays the main results from Experiment 2. Most important, same-case stems were completed more accurately than different-case stems when items were presented directly to the right hemisphere (98.2% versus 95.5%),  $F_1(1,62) = 10.3$ ,  $P < .01$ ,  $F_2(1,62) = 9.58$ ,  $P < .01$ , for the simple effect contrast; however, same-case stems were not completed more accurately than different-case stems when items were presented directly to the left hemisphere (97.3% versus 97.1%),  $F_1 < 1$ ,  $F_2 < 1$ , for the simple effect contrast. In fact, the interaction between type of encoding and test hemisphere was significant,  $F_1(1,31) = 7.54$ ,  $P < .01$ ,  $F_2(1,31) = 6.21$ ,  $P < .05$ . This pattern of results did not differ depending on whether lowercase or uppercase stems were presented at

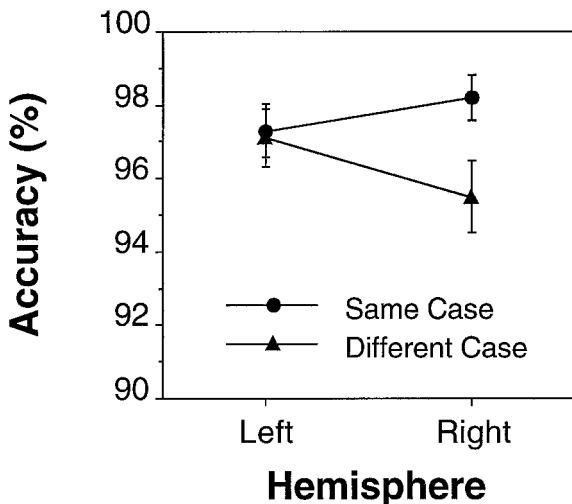


FIG. 2. Results from Experiment 2, in which participants completed single-completion word stems during test after viewing whole prime words for half a second each during initial encoding. Percentage of accurate word-stem completion is displayed as a function of hemisphere of direct stem presentations and type of initial encoding of corresponding prime words. Error bars indicate standard errors of the mean.

test,  $F_1 < 1$ ,  $F_2 < 1$ , for the three-way interaction between type of encoding, test hemisphere, and letter case of test stems.

In addition, same-case stems (97.8%) were completed more accurately than different-case stems (96.3%) in a significant effect in the first analysis,  $F_1(1,31) = 4.19$ ,  $P < .05$ , but in an effect that approached significance in the other analysis,  $F_2(1,31) = 4.01$ ,  $P < .06$ , for the main effect of type of encoding. No other effects approached significance in these analyses (all other  $P$ s  $> .25$ ).

Also, as in Experiment 1, we conducted additional analyses to test whether the important pattern of results was due to our having to repeat presentations of the same stems across blocks during the test phase (note, however, that each item was presented directly to different hemispheres across test blocks). We analysed the results from the first test block alone, and we found the same pattern of results as in the previous analyses (including both test blocks). Most important, the two-way interaction between type of encoding and test hemisphere was marginally significant,  $F_1(1,31) = 3.75$ ,  $P < .07$ ,  $F_2(1,31) = 3.31$ ,  $P < .08$ , but the three-way interaction between type of encoding, test hemisphere, and letter case of test stems did not approach significance,  $F_1(1,31) = 1.42$ ,  $P > .20$ ,  $F_2 < 1$ . Thus, repetition of test stems across test blocks apparently was not responsible for the important pattern of results.

## Combined Results

The most important finding in this study was that the interaction between type of encoding and test hemisphere was not significant in Experiment 1 (see Fig. 1) but was significant in Experiment 2 (see Fig. 2). Thus, it would be prudent to test this difference across experiments directly. To do so, we conducted a final repeated-measures analysis of variance on the combined data from Experiments 1 and 2, using experiment as a between-participants independent variable. We tested the appropriate interaction contrast, specifying the *a priori* predictions of no case-specific priming in direct left or right hemisphere test presentations in Experiment 1, but case-specific priming in direct right but not left hemisphere test presentations in Experiment 2. The effect was in fact significant for both untransformed data,  $F_1(1,62) = 7.31$ ,  $P < .01$ , and transformed data,  $F_2(1,62) = 7.83$ ,  $P < .01$ , confirming the main conclusions from this study.

## Discussion

The most important result was that case-specific priming was greater when test stems were presented directly to the right hemisphere than when they were presented directly to the left hemisphere (in analyses of both untransformed and transformed data). This finding did not differ depending on whether test stems were presented in lowercase or uppercase letters, also in both analyses. In addition, this pattern of results, obtained with single-completion stems, replicates the pattern of results obtained with multiple-completion stems

(Marsolek et al., 1992, 1994, 1996). Thus, results obtained with single-completion stems provide further support for the theory that a specific visual-form subsystem operates more effectively than an abstract visual-form subsystem in the right hemisphere, whereas an abstract visual-form subsystem operates more effectively than a specific visual-form subsystem in the left hemisphere. Apparently, the impoverished visual input during encoding had the effect that a specific subsystem contributed to processing to a greater degree relative to an abstract subsystem in this experiment than in Experiment 1 (in which an abstract subsystem dominated processing). With a specific subsystem disadvantaged relative to an abstract subsystem in Experiment 1, it was not able to contribute to robust case-specific priming effects (as it did in Experiment 2).

## GENERAL DISCUSSION

This study was prompted by a discrepancy in hemispheric asymmetries between previous word-stem-completion studies (using multiple-completion stems; Marsolek et al., 1992, 1994, 1996) and a perceptual identification experiment (Koivisto, 1996). In the former studies, case-specific priming was obtained when test items were presented directly to the right hemisphere but not when they were presented directly to the left hemisphere, in robust effects. However, in the latter experiment, the right-hemisphere advantage for case-specific priming was not robust, in that it was evident only when uppercase items were presented at test and not when lowercase items were presented at test. Thus, we examined possible explanations for the discrepant findings.

In Experiment 1, prime words were presented centrally for three seconds each during encoding, and single-completion stems were presented laterally during test. The results indicated that differences between stem-completion and perceptual-identification test tasks *per se* do not explain the empirical discrepancy; priming results very much like those from the perceptual-identification experiment were obtained in a stem-completion experiment with single-completion stems. Instead, the way in which test items constrain correct responses could explain the discrepancy; a single correct response per test item appears to disadvantage contributions to priming from a specific visual-form subsystem, which may explain why results very similar to those from perceptual identification were obtained in a stem-completion experiment with single-completion stems.

Experiment 2 was conducted to test whether the perceptual demands of the encoding task in Experiment 1 may have been responsible for the lack of robust case-specific priming. In Experiment 2, prime words were presented centrally for only half a second each during encoding, and single-completion stems were presented laterally during test. The results indicated that a more perceptually demanding encoding task led to greater case-specific priming. Most important, letter-case-specific priming was obtained when test items were presented directly to the right hemisphere but not when they were presented directly to the

left hemisphere, in a robust effect that did not depend on the letter case of the test items.

These results, combined with the results from previous studies (Burgund & Marsolek, 1997; Marsolek, 1995, in press; Marsolek et al., 1992, 1994, 1996), provide further support for the theory that a specific visual-form subsystem operates more effectively than an abstract visual-form subsystem in the right hemisphere, whereas an abstract visual-form subsystem operates more effectively than a specific visual-form subsystem in the left hemisphere. Moreover, in a new finding, these results support the hypothesis that the processing demands from the (test and encoding) tasks and stimuli greatly influence the patterns of priming produced by these subsystems.

Although the discussion in this article is on priming as an implicit measure of memory, the visual-form subsystems underlying the present priming effects can apparently contribute to explicit memory as well. Marsolek et al. (1994; cf. Schacter, 1994) used a coupling of divided-visual-field findings and positron-emission-tomography results to conclude that neocortical visual-form subsystems can support implicit memory for visual forms independently of hippocampal subsystems *and* can interact with hippocampal subsystems to support explicit memory for visual forms (cf. Marsolek & Field, in press). Either way, representations in the visual-form subsystems are crucial for supporting the effects, and these are the representations of concern here. For present purposes, it may not be important whether hippocampal interactions were involved in the memory effects; this would only affect the explicit/implicit nature of the effects, but not the main questions of interest (e.g. regarding case-specific memory effects for familiar visual forms, and whether task and stimulus demands affect them in interesting ways).

It may be important to emphasise that the consistently high accuracy rates observed in both experiments apparently did not compromise the conclusions. One could suggest that a ceiling effect was at work, such that real differences across experimental conditions were obscured by the pressure that accuracy rates could not be substantially higher than they were. However, it should be noted that such a ceiling effect would work *against* the possibility of finding a significant three-way interaction effect (between type of encoding [same vs. different case], test hemisphere, and letter case of test items), yet one was found in Experiment 1. Likewise, such a ceiling effect would work *against* the possibility of finding a significant type of encoding (same vs. different case) by test hemisphere interaction, yet one was found in Experiment 2. Furthermore, if a ceiling were such that it allowed only one of those two kinds of interaction to be observed, there would be no way to explain why one interaction was observed in Experiment 1 yet the other interaction was observed in Experiment 2 (accuracy rates were high in both experiments). Thus, the predicted patterns of differences across conditions were statistically significant despite rates that were close to ceiling. Moreover, the important statistical effects in both experiments were either significant or nonsignificant according to analyses of *both*

untransformed and arcsine-transformed accuracy rates, in ways that were in line with the theory.

To go further, one could suggest that, when some participants produced 100% accuracy in some experimental conditions, their performance in those conditions could have been qualitatively different without the ceiling, preventing useful conclusions from these experiments. However, the best predictors for performance in those conditions, if accuracy had not been 100%, would be the performance of the other participants who did not yield 100% accuracy in those conditions, which of course was the performance that produced the statistically significant effects. Also, given that different significant interactions were observed across the two experiments, any simple qualitative difference that could have been found (without a ceiling) in the conditions that produced 100% accuracy for some participants could not explain the main results from both experiments. In a sense, the results from Experiment 2 provide an existence proof against the argument that a ceiling effect prevented the critical two-way interaction from being significant in Experiment 1, and the results from Experiment 1 provide the same with respect to the three-way interaction in Experiment 2. Finally, and perhaps even more important, it is highly unlikely that a ceiling effect is responsible for the lack of case-specific priming in direct left hemisphere presentations in both experiments, given that a large number of previous experiments produced the same lack of effect (Burgund & Marsolok, 1997; Marsolek et al., 1992, 1994, 1996), despite the fact that performance did not approach ceiling or floor levels in any of them.

It may be important to note that horizontal presentations of word stems also apparently did not compromise the conclusions. The first letters of each stem were presented closer to the fovea in right visual-field presentations than in left visual-field presentations, thus one could suggest that the more informative part of a stem (or other such information) was closer to the fovea in the former condition than in the latter. However, the important results from this study were the significant interactions between visual field of stem presentation and the other variables, hence any reasonably simple difference between left and right visual-field presentations could not be used to explain the main results.

Therefore, one of our conclusions is that stimulus demands during encoding play an important role in determining which subsystems will store information that supports repetition priming effects (for similar effects in object recognition, see Marsolek, in press). We suspect that such demands may differ depending on whether old, pre-existing representations are activated during the experiment to support priming or new, original representations are created for the first time during the experiment to support priming. Sciamia and Rubie (1997) presented mixed-case words (e.g. "sKiRt" and "SkIRt") during encoding and test, and found greater case-specific priming (e.g. greater priming when "sKiRt" primed "sKiRt", compared with when "SkIRt" primed "sKiRt") when test items were presented directly to the right hemisphere than to the left in a word-naming experiment. However, one interesting qualification was that this effect was

obtained when words were presented six times during encoding but not when words were presented only once during encoding. Note that, in the present article, case-specific priming was greater when test stems were presented directly to the right hemisphere than to the left, but only when words were presented briefly during encoding and not when words were presented for a longer duration during encoding. Why does case-specific priming in the right hemisphere rely on frequent encoding in one study, but brief encoding in another? It may be important to note that Sciamma and Rubie used stimuli (e.g. "SKirT") that likely were *novel* visual wholes for most participants, whereas we used stimuli (e.g. "beyond") that were highly familiar visual wholes. By "visual wholes," we mean the entire visual form taken as a single complex structure (see Marsolek et al., 1996). We suspect that longer or more frequent encoding exposures are needed for substantial case-specific priming when the stimuli are novel usual wholes than when the stimuli are familiar visual wholes. In both cases though, a specific visual-form subsystem should be crucial for the information storage (see Marolek et al., 1996). Research currently is under way to test this possibility.

Indeed, the demands from various methodological aspects of an experiment may be important for predicting the processing that occurs in the underlying neural subsystems. Just as processing demands from the nature of the task (Experiment 1) and from the quality of the stimuli (Experiment 2) play crucial roles in predicting priming effects, processing demands from the familiarity of the stimuli and other such variables may play important roles as well.

Manuscript received 28 February 1998

Revised manuscript received 4 August 1998

## REFERENCES

- 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.
- 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.
- Christman, S. (1989). Perceptual characteristics in visual laterality research. *Brain and Cognition* *11*, 238-257.
- Clarke, R.G.B., & Morton, J. (1983). Cross modality facilitation in tachistoscopic word recognition. *Quarterly Journal of Experimental Psychology*, *35A*, 79-96.
- 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.
- Francis, W.N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton Mifflin.
- Gazzaniga, M.S. (1989). Organisation of the human brain. *Science*, *245*, 947-952.
- 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.
- Hellige, J.B. (1976). Changes in same-different laterality patterns as a function of practice and stimulus quality. *Perception & Psychophysics*, *20*, 267–273.
- Hellige, J.B. (1980). Effects of perceptual quality and visual field of probe stimulus presentation on memory search for letters. *Journal of Experimental Psychology: Human Perception and Performance*, *6*, 639–651.
- Hellige, J.B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA: Harvard University Press.
- Howell, D.C. (1987). *Statistical methods for psychology* (2nd edn.). Boston: Duxbury Press.
- 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.
- Johnson, P.O. (1949). *Statistical methods in research*. New York: Prentice-Hall.
- Keane, M.M., Gabrieli, J.D.E., Fennema, A.C., Growdon, J.H., & Corkin, S. (1991). Evidence for a dissociation between perceptual and conceptual priming in Alzheimer's disease. *Behavioural Neuroscience*, *105*, 326–342.
- Kirsner, K., Milech, D., & Standen, P. (1983). Common and modality-specific processes in the mental lexicon. *Memory & Cognition*, *11*, 621–630.
- 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.
- Kosslyn, S.M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review*, *94*, 148–175.
- 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. (in press). Dissociable neural subsystems underlie abstract and specific object recognition. *Psychological Science*.
- 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., & Field, J.E. (in press). Perceptual-motor sequence learning of general regularities and specific sequences. *Journal of Experimental Psychology: Human Perception and Performance*.
- 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., 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.
- Moscovitch, M. (1983). Laterality and visual masking: Interhemispheric communication and the locus of perceptual asymmetries for words. *Canadian Journal of Psychology*, *37*, 85–106.
- Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113.
- Posner, M.I., & McCandliss, B.D. (1993). Converging methods for investigating lexical access. *Psychological Science*, *4*, 305–309.
- Rajaram, S., & Roediger, H.L. (1993). Direct comparison of four implicit memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 765–776.

- 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.
- Sciama, S.C., & Rubie, A.M.G. (1997, March). *The influence of word-form representation in reading*. Presented at the Cognitive Neuroscience Society Annual Meeting, Boston, MA.
- Sergent, J., & Hellige, J.B. (1986). Role of input factors in visual-field asymmetries. *Brain and Cognition*, 5, 174–199.
- Webster's Vest Pocket Dictionary*. (1989). Springfield, MA: Merriam-Webster.

Copyright of *Laterality* is the property of Psychology Press (T&F) and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.