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Letter-Case-Specific Priming in the Right Cerebral Hemisphere with a Form-Specific Perceptual Identification Task

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In a form-specific perceptual identification task, subjects identify and write letter strings in the same letter case as they appear on a computer display. Letter-case-specific repetition priming was observed in this task when test items were presented directly to the right hemisphere, but not when they were presented directly to the left hemisphere, similar to results in previous word-stem completion experiments. This pattern of results was not obtained in a standard perceptual identification task. Results indicate that a specific visual-form subsystem, but not an abstract visual-form subsystem, operates more effectively in the right hemisphere than in the left, and task demands greatly affect which subsystems are recruited in different priming tests. © 1997 Academic Press

Growing evidence suggests that functional asymmetries are best understood in terms of a componential, cognitive neuroscience framework. In this framework, whole abilities or tasks are not lateralized; rather, relatively circumscribed functional components operate asymmetrically in the brain (for reviews, see Hellige, 1993; Kosslyn, 1987; Posner & McCandliss, 1993). That is, neural processing subsystems perform somewhat circumscribed functions relatively independently, and separate subsystems appear to operate more or less effectively in different hemispheres.

A necessary aspect of using this framework to provide theoretical explanations for an ability or task is to clarify the simple component functions of the relevant subsystem and to consider how these functions may conspire to accomplish different tasks. For example, it is unlikely that the same set

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of subsystems underlies performance when one normally reads the word ‘‘cat’’ as well as when one is asked to ‘‘read’’ the word produced by a ‘‘t’’ preceded by an ‘‘a’’ preceded by a ‘‘c.’’ Nonoverlapping sets of component functions likely underlie the two tasks (i.e., perhaps phonological subsystems or visual-imagery mechanisms are recruited only in the latter task, etc.). In other words, careful analyses of information processing tasks and the demands that they place on the underlying mechanisms are needed to hypothesize how component processing subsystems underlie performance in different tasks.

In the domain of visual form recognition, recent evidence indicates that relatively independent subsystems are involved (Marsolek, 1995). Although these subsystems may be only weakly modular, they appear to operate relatively independently to achieve different goals. One subsystem performs abstract visual-form (AVF) processing, such as recognizing that the lower- and uppercase versions of the same word belong to the same abstract category of form, and operates more effectively in the left cerebral hemisphere (LH) than in the right. Another subsystem performs specific visual-form (SVF) processing, such as distinguishing the lower- and uppercase versions of the same word, and operates more effectively in the right cerebral hemisphere (RH) than in the left. These subsystems are useful for recognizing abstract categories and specific instances of familiar forms, respectively.[1] Results from word-stem completion priming experiments provide evidence that AVF and SVF subsystems operate relatively independently (Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996; Marsolek, Squire, Kosslyn, & Lulenski, 1994; see also Buckner et al., 1995; Squire et al., 1992). Interestingly, results from a recent word identification priming experiment do not support the separate subsystems hypothesis (Koivisto, 1995).

In this article, we summarize the apparently inconsistent results obtained with word-stem completion tasks and with a word identification task. We then hypothesize why different patterns of results are obtained and test alternative explanations. Results clarify the seemingly inconsistent findings and indicate that analyses of task demands are crucial for determining whether different sets of processing subsystems contribute to performance in different priming tasks.

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[1] An AVF subsystem likely processes the relatively invariant information that is common to lower- and uppercase versions of the same letter or word in order to match them to the same visual representation (Marsolek, 1995). In contrast, an SVF subsystem likely processes the visually distinctive information between lower- and uppercase versions of the same letter or word in order to match them to different visual representations (Marsolek, Schacter, & Nicholas, 1996). Note that we do not hypothesize that an AVF subsystem underlies processing of word meanings per se, whereas an SVF subsystem underlies processing of visual forms; both subsystems process and store visual-form information, albeit in different ways to achieve different goals.

DISCREPANT FINDINGS ACROSS WORD PRIMING TASKS

In word-stem completion priming experiments, subjects complete visually presented word stems after processing a list of visually presented words. Half of the primed stems are presented at test in the same letter case as that in which their corresponding words were presented during encoding, and half of the primed stems are presented in the different letter case. Priming is measured as a greater tendency for subjects to produce previously processed words than unprimed words as stem completions. In this task, greater repetition priming is found when test stems are presented in the same letter case as previously processed words than when they are presented in the different letter case. Moreover, this case-specific priming effect is observed when test stems are presented directly to the RH (in the left visual field), but not when they are presented directly to the LH (in the right visual field). Furthermore, different letter-case priming does not differ depending on which hemisphere initially receives the test stems. Thus, evidence from word-stem completion studies provides compelling support for the separate subsystems hypothesis (Marsolek et al., 1992, 1994, 1996).[2]

Conversely, support for the separate subsystems hypothesis is not obtained when a word identification task is used to measure priming (Koivisto, 1995). In this task, subjects first read a list of words and then identify these words as well as a set of intermixed unprimed words that are flashed briefly in the right or left visual fields. As in the word-stem completion experiments, half of the primed words are presented in the same letter case as during encoding, and half are presented in the different letter case. Priming is measured as a greater tendency for subjects to correctly identify previously processed words compared with unprimed words. The important result is that, contrary to findings with word-stem completion tasks, a RH advantage for case-specific priming is not found. Thus, support for the separate subsystem hypothesis is not obtained, and an explanation for the discrepant findings from word-stem completion and word identification is needed.

SPECIALIZED WORD SUBSYSTEM?

A potential reason why results from word-stem completion support the separate subsystems hypothesis, but results from word identification do not,

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[2] In divided-visual-field presentations, the contralateral hemisphere receives the information before the ipsilateral hemisphere and probably also receives higher quality information than the ipsilateral hemisphere (e.g., Dimond, Gibson, & Gazzaniga, 1972; Gross, Rocha-Miranda, & Bender, 1972). Thus, if the characteristic processing associated with an SVF subsystem (e.g., case-specific priming) is performed more efficiently when higher quality input is processed initially by the RH, whereas the characteristic processing associated with an AVF subsystem (e.g., different letter-case priming) is not, then the two subsystems must operate at least relatively independently. An interaction such as this, between type of process and hemisphere of initial input, is needed to make strong claims from results in divided-visual-field experiments (see Hellige, 1983).

comes from the following reasoning. The word identification task may rely on a subsystem that is specialized for processing *words* per se (Bowers, 1996; Morton, 1979), whereas the word-stem completion task may rely on a number of diverse subsystems, some of which may not be specialized for processing words alone. Experiments examining case-specific priming for words and pseudowords (Bowers, 1996; Feustel, Shiffrin, & Salasoo, 1983) provide evidence for the idea that word identification is supported by subsystems that are word-specific, in that they are distinct from subsystems that are recruited for pseudoword identification. For example, when subjects identify lists of words, they do not exhibit case-specific priming, yet when they identify lists of pseudowords, they do exhibit case-specific priming. Furthermore, case-specific priming is found for both pseudowords and words when they are intermixed (Bowers, 1996). These findings suggest that the inclusion of pseudowords in the stimulus set changes how the stimuli are processed, and different subsystems may contribute to priming in this task depending on whether pseudowords are included. Thus, identification of words may be supported largely by an (abstract) subsystem that is devoted to processing words exclusively, whereas identification of intermixed pseudowords and words may be supported in part by other (more visually specific) subsystems that distinguish between lower- and uppercase versions of letter strings and are not specialized for processing words per se.

This theory suggests a possible reason for why results from the word identification experiment do not support the separate subsystems hypothesis. When only words are presented in an identification task, priming may be supported primarily by a specialized word subsystem. Contributions from an SVF subsystem may be obscured in this task, thus explaining the lack of a RH advantage for case-specific priming in word identification (Koivisto, 1995). In contrast, when both words *and* pseudowords are presented, priming in an identification task may be supported by a number of diverse subsystems, some of which may not be specialized for words. If so, an SVF subsystem that operates more effectively in the RH than in the LH may contribute significantly to priming under these identification conditions. We test this prediction in the following experiment.

EXPERIMENT 1

Subjects first read a list of words and pseudowords that are intermixed and presented one at a time in the central visual field, during the encoding phase of this experiment. Then, during the test phase, they perceptually identify words and pseudowords that are intermixed and presented one at a time briefly in the left or right visual fields. It is important to note that subjects report letter strings by writing them on a response sheet in whatever manner they choose, which is the standard procedure in perceptual identification tasks. If a specialized word subsystem mediates priming in the word identification task (as in Koivisto, 1995), whereas other subsystems that are not specialized for words (e.g., an SVF subsystem) contribute significantly to priming in the word *and* pseudoword identification task (as in this experiment), then a RH advantage for case-specific priming should be found.

Method

Subjects. Sixteen male and 16 female undergraduate students at Harvard University or at the University of Arizona volunteered to participate for pay or for course credit. All were fairly strongly right-handed as assessed through the Edinburgh Handedness Inventory (mean laterality quotient = .79; range = .60–1.0; Oldfield, 1971).

Design. Four within-subjects variables were manipulated: type of letter string (word vs pseudoword), type of initial encoding (primed same case vs primed different case vs unprimed), hemisphere of initial test presentations (LH vs RH), and letter case of test presentations (lowercase vs uppercase), creating a 2 × 3 × 2 × 2 within-subjects design.

Materials. The stimuli in this experiment were 256 letter strings (see Appendix). Half of the strings formed words and the other half formed pseudowords. All strings were either 4 or 5 letters in length. In addition, 10 letter strings (five words and five pseudowords) were employed for practice trials, and 4 letter strings (two words and two pseudowords) were used as buffer items in the encoding phase (two appearing at the beginning and two at the end of each encoding phase list) to attenuate primacy and recency effects.

The words were selected from the Kučera and Francis (1967) volume and were of low frequency in the language (one occurrence per million; Kučera & Francis, 1967). Low-frequency words were used because they have been found to produce greater case-specific priming effects in word identification than high-frequency words (Jacoby & Hayman, 1987). The pseudowords were created by changing one of the letters in each of the word strings, so that they remained easily pronounceable. In this way, each letter string had a word and a pseudoword counterpart with only one letter differentiating the two. This was done to assure that the pseudoword strings were highly similar to the word strings in almost every respect except for having meaning and usage in the English language.[3]

The 256 letter strings were divided into 32 sublists of 8 letter strings each. Four of the 8 letter strings in each sublist were words, and the other four were their pseudoword counterparts. Counterbalancing insured that no single subject saw both the words and the pseudowords in the same sublist of letter strings, so that priming from encoding the word version of a letter string on the identification of its pseudoword counterpart (or vice versa) was not possible. Therefore, each subject saw only half of each sublist of strings (for a total of 128 experimental items).

For each subject, 16 sublists (64 strings) were used for stimuli in the encoding phase as well as for stimuli in the test phase (these were primed test items) and the other 16 sublists (64 items) were used for stimuli in the test phase but not in the encoding phase (these were unprimed test items). Unprimed items were presented in the test phase to measure baseline probabilities of correctly identifying letter strings that had not been presented earlier in the experiment.

In order to counterbalance the primed items across subjects, the 16 sublists were rotated through the 16 primed conditions defined by orthogonally combining type of letter string (word vs pseudoword), letter case between initial encoding and subsequent test (same case vs differ-

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[3] After completion of this study, it was noticed that one of the pseudowords was formed by mistakenly changing two of the letters instead of one (fray to glay). However, the pseudoword (glay) was still easily pronounceable and very similar to the word strings except for having meaning and usage in English.

ent case), hemisphere of direct test presentations (LH vs RH), and letter case of test presentations (lowercase vs uppercase). In addition, to counterbalance the unprimed items across subjects, the 16 sublists were rotated through the 8 unprimed conditions defined by orthogonally combining type of letter string (word vs pseudoword), hemisphere of direct test presentations (LH vs RH), and letter case of test presentations (lowercase vs uppercase). Thus, each sublist represented each of the conditions an equal number of times across subjects. In addition, each sublist represented the primed and unprimed conditions an equal number of times across subjects.

Therefore, each subject was presented with 128 test trials. The words in 16 of the sublists (64 words) and the pseudowords in the other 16 of the sublists (64 pseudowords) were used as stimuli for any one subject. During the test phase, 8 of the word sublists (32 words) and 8 of the pseudoword sublists (32 pseudowords) were primed, and the other 8 word sublists (32 words) and 8 pseudoword sublists (32 pseudowords) were unprimed. Within each of the 8 primed word sublists (32 words) and 8 primed pseudoword sublists (32 pseudowords), 4 were presented in the same letter case between the encoding phase and the test phase (16 same-case words and 16 same-case pseudowords) and 4 were presented in different letter cases between the encoding phase and the test phase (16 different-case words and 16 different-case pseudowords). For each of the 4 primed same-case word and 4 primed same-case pseudoword sublists, 2 were presented directly to the LH (8 words and 8 pseudowords), one sublist in lowercase (4 words and 4 pseudowords) and the other sublist in uppercase (4 words and 4 pseudowords), and 2 were presented directly to the RH (8 words and 8 pseudowords), one sublist in lowercase (4 words and 4 pseudowords) and the other sublist in uppercase (4 words and 4 pseudowords). Likewise, for each of the 4 primed different-case word and 4 primed different-case pseudoword sublists, 2 were presented directly to the LH (8 words and 8 pseudowords), one sublist in lowercase (4 words and 4 pseudowords) and the other sublist in uppercase (4 words and 4 pseudowords), and 2 were presented directly to the RH (8 words and 8 pseudowords), one sublist in lowercase (4 words and 4 pseudowords) and the other sublist in uppercase (4 words and 4 pseudowords). Finally, within each of the 8 unprimed word sublists and 8 unprimed pseudoword sublists, 4 were presented directly to the LH (16 words and 16 pseudowords), two sublists in lowercase (8 words and 8 pseudowords) and the other two sublists in uppercase (8 words and 8 pseudowords), and 4 were presented directly to the RH (16 words and 16 pseudowords), two sublists in lowercase (8 words and 8 pseudowords) and the other two sublists in uppercase (8 words and 8 pseudowords). Thus, 8 trials contributed to the cell means in unprimed conditions and 4 trials contributed to the cell means in primed conditions for each subject.

The stimuli were presented on an AppleColor High Resolution RGB Monitor with a Polaroid CP-50 filter placed over it to reduce glare. Stimulus presentation was controlled by a Macintosh II computer. All letters were presented in black against a white background in a 24-point, bold Helvetica font (letter size varied, but was approximately 5 × 6 mm for most letters). A 2-mm dot (subtending 0.23° of visual angle) served as the central fixation point that indicated the beginning of a trial. During the encoding phase, the letter strings appeared at the center of the monitor. In the test phase, the letter strings were presented in the left or right visual field such that the center of each string was 2.87° from the center of the monitor, and the inner edge of a string never appeared closer than 1.03° from the center. Finally, a chin rest was employed to keep subjects' eyes approximately 50 cm from the monitor.

Procedure

Each subject was tested in individually conducted sessions. Each experimental session had an encoding phase and a test phase.

Encoding phase. In this phase, subjects silently read 64 letter strings (plus four filler strings, two at the beginning and two at the end of a list), and rated them, with a 5-point scale, on their ''readability'' (i.e., how easy/difficult it was to read each string). This task was used because it may be especially likely to produce subsequent case-specific priming in word identification tasks (see Graf & Ryan, 1990). Subjects were instructed to rely on visual information, disregarding whether the letter string was a genuine word or not, when making their judgments.

Each trial began with the presentation of the fixation point, which appeared at the center of the screen for 500 ms. Immediately thereafter, a letter string was presented centrally for 3 s. Subjects pressed a number key from 1 to 5 on the computer keyboard to indicate their rating of the letter string's ''readability.'' Subjects were asked to make each response after the string disappeared, and the next trial began automatically 1 s after a number key was pressed. Thus, the average presentation rate was about 5 s per letter string.

Each subject viewed 64 letter strings plus the four filler strings during the encoding phase. The list of 68 letter strings was presented twice in succession, to encourage substantial priming for each item. Subjects were told to follow the same instructions in the second iteration as they had followed in the first. For each of the two successive list presentations, a different pseudo-random order was used for the nonfiller items. These orders were random with the constraints that no more than 3 letter strings appeared consecutively that were words or pseudowords, would be presented in the same or different letter case at test, would be presented in the right or left visual field at test, or were in upper- or lowercase letters.

Test phase. This phase began approximately 6 min after the encoding phase ended. A practice session of 10 trials intervened between the encoding and test phases. The practice trials were conducted like test trials except that practice letter strings were presented for longer durations than the test letter strings. The exposure durations for the practice trials started at 116 ms and decreased in 17/16 ms increments every two trials until the final two trials, in which strings were presented for 50 ms each (durations of 116, 100, 83, 67, and 50 ms). The practice trials were conducted in this manner so that subjects could get accustomed to short exposure durations gradually while becoming familiarized with the test procedure. Subjects were informed that in each test trial a letter string would appear briefly, either to the left or the right of the center of the monitor screen. They were instructed to write down the letter string as accurately as possible on their answer sheet, with no special instructions regarding how to print or write the letters, and to push the space bar when they were ready to proceed to the next trial.

A test trial began with the presentation of the fixation point at the center of the screen for 500 ms. Subjects were encouraged to focus their attention on the fixation point when it appeared and not to anticipate which side of the fixation point the next letter string would appear. Immediately after the fixation point disappeared, a letter string appeared in the left or right visual field for 17 ms. A blank screen followed the presentation of the letter string and remained until the subject had written down his or her response and pushed the space bar to begin the next trial. After the space bar was pushed, 1 s elapsed before the next trial began.

The 128 test letter strings were presented in different pseudo-random orders for each subject. The orders were random with the constraints that no more than 3 letter strings appeared consecutively that were words or pseudowords, were primed or unprimed, were presented in the same or different letter case compared with initial encoding (for primed items), were presented in the same visual field, or were presented in lower- or uppercase letters.

Results

In this experiment, an identification response was scored as correct only if the same letters were written in the same order as those presented on the screen. Percentage correct identification of letter strings was analyzed in a four-way repeated measures analysis of variance (ANOVA). Type of letter string (word vs pseudoword), type of initial encoding (primed same case vs primed different case vs unprimed), hemisphere of direct test presentations

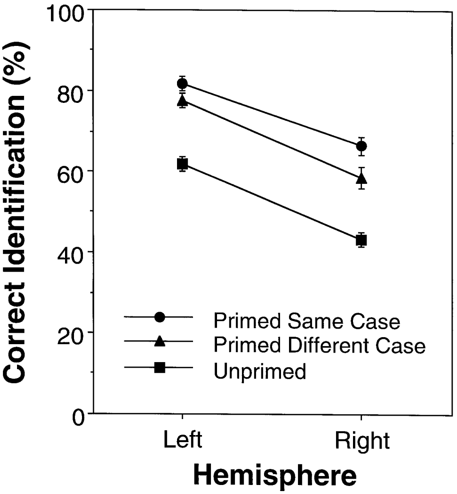

FIG. 1. Results from Experiment 1. Percentage correct identification of letter strings (in a standard perceptual identification task) is displayed as a function of hemisphere of direct test presentation and type of initial encoding of the stimulus. Error bars indicate standard errors of the mean.

(LH vs RH), and letter case of test presentations (lowercase vs uppercase) were within-subjects independent variables.

Figure 1 illustrates the results from this experiment. For items presented directly to the RH, both primed same-case (67%) and primed different-case items (59%) were identified more accurately than unprimed items (43%); likewise, for items presented directly to the LH, both primed same-case (82%) and primed different-case items (78%) were identified more accurately than unprimed items (62%), all *p*s $< .0001$, for the contrast effects testing a priori predictions. These results indicate that significant priming was obtained in all four of those conditions.

However, the most important result in this experiment was that type of initial encoding (primed same-case, primed different-case, and unprimed items) did not differ depending on whether items were presented directly to the RH or directly to the LH, $F(2, 62) < 1$, for the interaction between type of initial encoding and hemisphere of direct test presentations. This effect did not even approach significance, hence there was no indication of a RH advantage for case-specific priming. In addition, type of initial encoding and hemisphere of direct test presentations did not interact with type of letter string (word vs pseudoword) in a three-way interaction, $F(2, 62) < 1$, indicating that the lack of a RH advantage for case-specific priming did not differ for words versus pseudowords.

The following effects were significant in this analysis, however (all other *p*s $> .08$). Primed same-case (74%), primed different-case (68%), and unprimed items (53%) were identified with differing accuracy, $F(2, 62) = 68.79$, $p < .001$, $MS_e = 461.63$, for the main effect of type of initial encoding. In an effect replicating previous studies (Beaumont, 1982; Mishkin & Forgays, 1952; Young, Ellis, & Bion, 1984), items presented directly to the LH (74%) were identified more accurately than those presented directly to the RH (56%), $F(1, 31) = 45.70$, $p < .001$, $MS_e = 1305.06$, for the main effect of hemisphere of direct test presentations. Words were identified more accurately than pseudowords (73 and 57%, respectively), $F(1, 31) = 165.97$, $p < .001$, $MS_e = 317.59$, for the main effect of type of letter string. In a result similar to recent findings from Bowers (1996), the effect of type of initial encoding (primed same-case, primed different-case, and unprimed items) was greater for pseudowords (69, 58, and 43%, respectively) than for words (79, 78, and 62%, respectively), $F(2, 62) = 5.76$, $p < .01$, $MS_e = 360.27$, for interaction between type of initial encoding and type of letter string. Finally, the advantage for identifying words over pseudowords was greater for items presented directly to the RH (66% vs 47%, respectively) than for items presented directly to the LH (81% vs 67%, respectively), $F(1, 31) = 5.65$, $p < .05$, $MS_e = 238.81$, for the interaction between type of letter string and hemisphere of direct test presentations.

Discussion

The results from this word and pseudoword identification experiment replicate the main finding from an earlier word identification experiment (Koivisto, 1995). In both experiments, no RH advantage for case-specific priming is obtained, unlike results from word-stem completion experiments. Hence, the idea that word identification relies on a specialized word subsystem, but word and pseudoword identification and stem completion tasks do not, cannot explain the discrepancy in findings obtained on identification and stem completion tasks. Next, we use task analyses to suggest a different explanation for why previously published results from the identification task do not support the separate subsystems hypothesis, whereas previously published results from the stem completion task do support that hypothesis.

TASK DEMANDS AND RECRUITMENT OF DIFFERENT SUBSYSTEMS

Another possibility is that the requirements for the identification and stem completion tasks place qualitatively different demands on the underlying processing mechanisms. In word-stem completion, subjects respond by completing a stem to form the first word that comes to mind. While this task restricts the subject by requiring an appropriate stem completion, there are *many* correct responses that the subject could produce in any one trial (i.e., each stem can be completed to form at least 10 common words; Marsolek et al., 1992, 1994, 1996). Because a wide range of correct responses can be produced in each trial, different types of information may be useful for completing each stem, and a number of diverse subsystems (including an SVF subsystem) may contribute to performance. Indeed, even though case-specific priming is commonly found in stem completion (Marsolek et al., 1992, 1994, 1996), many researchers have observed that stem-completion priming can be obtained in visual tests following initial auditory encoding of words (Graf, Shimamura, & Squire, 1985; Marsolek et al., 1992; Rajaram & Roediger, 1993), and others have suggested that stem-completion priming is supported in large part by semantic subsystems (Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991).[4]

Conversely, in perceptual identification, subjects must report the *one* correct letter string that is presented in each trial. The constrained nature of this task, relative to stem completion, may create a situation in which the most efficient subsystem is recruited very frequently to accomplish the task. Under standard identification conditions, processing of letter-case information is not required, thus an SVF subsystem may not be very useful. Rather, an AVF subsystem that operates more effectively in the LH than in the RH may be extremely useful, because this subsystem should ignore specific case information in order to recognize efficiently the abstract category of visual form to which an input corresponds (Marsolek, 1995). Indeed, results from several identification studies indicate that only small and inconsistent case-specific priming effects are found typically (Bowers, 1996; Clarke & Morton, 1983; Feustel et al., 1983; Jacoby & Hayman, 1987; Rajaram & Roediger, 1993). Yet, priming in identification tasks appears to be supported in large part, although perhaps not exclusively, by visual subsystems (Clarke & Morton, 1983; Jacoby & Dallas, 1981; Keane et al., 1991; Kirsner, Milech, & Standen, 1983; Rajaram & Roediger, 1993). Furthermore, LH advantages have been obtained for processing words and pseudowords in divided-visual-field studies (Experiment 1 above; Beaumont, 1982; Mishkin & Forgays, 1952; Young et al., 1984), and LH activations have been obtained during processing of words and pseudowords in neuroimaging studies (Petersen, Fox, Snyder, & Raichle, 1990), in line with the hypothesis that an AVF subsystem operates more effectively in the LH than in the RH. Hemispheric asymmetries are not found in unprimed, baseline stem completion performance (Marsolek et al., 1992, 1994, 1996). Therefore, different sets of processing subsystems may be recruited typically in stem completion and standard perceptual identification tasks: a variety of subsystems (including an

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[4] It may be important to note that any greater likelihood of finding cross-modality priming in stem completion experiments compared with identification experiments cannot account for the discrepant case-specific priming effects in RH presentations between stem completion and word identification tests. Although a RH advantage is obtained for case-specific within-modality priming in stem completion, a RH advantage is not found for cross-modality priming in stem completion (Marsolek, Kosslyn, & Squire, 1992).

SVF subsystem) in stem completion, but primarily an AVF subsystem in standard perceptual identification.

This reasoning suggests that the demands of the standard perceptual identification task are responsible for the inability to obtain a RH advantage for case-specific priming with that task. One way to test this hypothesis is to determine whether these task demands can be altered so that the subsystems that contribute to priming during perceptual identification are similar to those that contribute to priming during stem completion. In particular, the identification task could be modified so that case-specific information is necessary for accurate performance. Under these conditions, an AVF subsystem would no longer be very efficient for the task, and an SVF subsystem would become essential for accurate performance. We test this possibility in the following experiment.

EXPERIMENT 2

As in Experiment 1, subjects first read a list of words and pseudowords presented in the central visual field, during the encoding phase. Then, subjects perceptually identify words and pseudowords presented briefly in the left or right visual fields. The crucial difference between the two experiments is that in this one subjects are asked to write each test letter string in the *same letter case* as it appears on the computer monitor, whereas in Experiment 1 they were not required to write letter strings in any special manner. Thus, we employ a *form-specific identification task,* rather than a standard perceptual identification task, to test the separate subsystems hypothesis. If an SVF subsystem, operating more effectively in the RH than in the LH, contributes greatly to perceptual-identification priming when task demands create a situation in which case-specific information is necessary for performance, then a RH advantage for case-specific priming should be found. However, if an SVF subsystem does not contribute greatly to priming when any sort of identification task is used, then no RH advantage for case-specific priming should be found, as in Experiment 1.

Method

Subjects. Sixteen male and 16 female University of Arizona students participated for course credit. All were fairly strongly right-handed as assessed through the Edinburgh Handedness Inventory (mean laterality quotient = .90; range = .60–1.0; Oldfield, 1971). None had participated in Experiment 1.

Materials and procedure. The materials and procedure were the same as those used in Experiment 1 with the following exception. During the test phase of this experiment, instead of instructing subjects simply to write down the letter string that appears on the screen, we instructed subjects to print each letter string in the *same letter case* as it appeared on the screen at test. Subjects were encouraged to print clearly on elementary school line-formatted handwriting paper, so that each letter could be clearly distinguished as being printed in lower- versus uppercase.

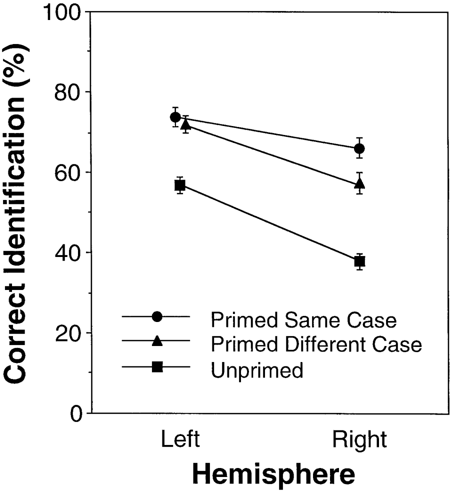

FIG. 2. Results from Experiment 2. Percentage correct identification of letter strings (in a form-specific perceptual identification task) is displayed as a function of hemisphere of direct test presentation and type of initial encoding of the stimulus. Error bars indicate standard errors of the mean.

Results

In this experiment, a response was scored as correct only when the same letters were written in the same order *and* in the same letter case as the letter string presented on the computer monitor. Percentage correct identification was analyzed in a four-way repeated measures ANOVA. Type of letter string (word vs pseudoword), type of initial encoding (primed same case vs primed different case vs unprimed), hemisphere of direct test presentations (LH vs RH), and letter case of test presentations (lowercase vs uppercase) were within-subjects independent variables.

Figure 2 illustrates the main results from this experiment. For items presented directly to the RH, both primed same-case (66%) and primed different-case items (57%) were identified more accurately than unprimed items (39%); likewise, for items presented directly to the LH, both primed same-case (74%) and primed different-case items (72%) were identified more accurately than unprimed items (57%), all *p*s $< .0001$, for the contrast effects testing a priori predictions. Thus, significant priming was obtained in all four of those conditions.

The most important result from this experiment however, was that, unlike in Experiment 1, the interaction between type of initial encoding (primed same case vs primed different case vs unprimed) and hemisphere of direct test presentations (RH vs LH) was significant, $F(2, 62) = 3.32$, $p < .05$, $MS_e = 433.70$. In particular, when letter strings were presented directly to the RH, primed same-case items were identified more accurately than primed different-case items (66 and 57%, respectively), $F(1, 124) = 11.52$, $p < .001$, $MS_e = 452.12$, for the simple effect contrast. However, when letter strings were presented directly to the LH, primed same-case items were not identified significantly more accurately than primed different-case items (74 and 72%, respectively), $F(1, 124) < 1$, for the simple effect contrast. Thus, these results clearly demonstrate a RH advantage for case-specific priming. Furthermore, type of initial encoding and hemisphere of direct test presentations did not interact with type of letter string (word vs pseudoword) in a three-way interaction, $F(2, 62) < 1$, indicating that the RH advantage for case-specific priming did not differ for words versus pseudowords.

The other significant effects in this analysis were the following (all other *p*s $> .10$). Replicating Experiment 1, primed same-case (70%), primed different-case (65%), and unprimed items (48%) were identified with differing accuracy, $F(2, 62) = 72.85$, $p < .001$, $MS_e = 470.54$, for the main effect of type of initial encoding. In an effect replicating Experiment 1 and previous studies (Beaumont, 1982; Mishkin & Forgays, 1952; Young et al., 1984), items presented directly to the LH (68%) were identified more accurately than those presented directly to the RH (54%), $F(1, 31) = 28.36$, $p < .001$, $MS_e = 1265.44$, for the main effect of hemisphere of direct test presentations. Also replicating Experiment 1, words (69%) were identified more accurately than pseudowords (53%), $F(1, 31) = 100.06$, $p < .001$, $MS_e = 533.01$, for the main effect of type of letter string. In an effect that was not found in Experiment 1, uppercase items (63%) were identified more accurately than lowercase items (58%), $F(1, 31) = 8.85$, $p < .01$, $MS_e = 545.38$, for the main effect of letter case of test presentations. Finally, in an interaction that approached significance, the advantage for identifying uppercase items more accurately than lowercase items was greater when they were presented directly to the RH (58% vs 50%, respectively) than when they were presented directly to the LH (69% vs 67%, respectively), $F(1, 31) = 3.82$, $p < .06$, $MS_e = 412.47$, for the interaction between hemisphere of direct test presentations and letter case of test presentations.

Finally, in order to insure that the results from this experiment were not attributable to the use of a strict scoring criterion (one that required responses to be printed in the same letter case as that in which the strings were presented, in order to be scored as correct), we also analyzed the results using the less strict scoring criterion that was used in Experiment 1 (one in which letter case of printed responses was irrelevant). Thus, each item was rescored for identity of strings only. Interestingly, only one item needed to be rescored; that is, there was only one case in which the correct letter string was written in the wrong letter case. In line with the hypothesis that an AVF subsystem operates more effectively in the LH than in the RH, this letter-case error occurred on an item presented to the LH. More important however, rescoring this item did not alter the main findings of Experiment 2. Therefore, the results from this experiment are not due to the strict scoring criterion that was used.

Discussion

The results from Experiment 2 clearly support the separate subsystems hypothesis. A RH advantage for case-specific priming is obtained, supporting the hypothesis that an SVF subsystem, unlike an AVF subsystem, operates more effectively in the RH than in the LH (Marsolek, 1995; Marsolek et al., 1992, 1994, 1996). This experiment utilized a form-specific identification task, not a standard identification task. Thus, findings from a form-specific identification task (this experiment), but not findings from a standard identification task (Experiment 1; Koivisto, 1995), corroborate results from previous word-stem completion experiments (Marsolek et al., 1992, 1994, 1996). Accordingly, differences in task demands between the standard perceptual identification task and the word-stem completion task, and the resulting differences in recruitment of different subsystems, appear to be responsible for the discrepancy in previously published results from studies using these tasks.

GENERAL DISCUSSION

In this article, we examine possible explanations for why stem completion tasks and a standard word identification task produce different patterns of results, in experiments that test the hypothesis that AVF and SVF subsystems operate relatively independently. In Experiment 1, we consider that the word identification task may rely on a subsystem specialized for processing words per se. To test this hypothesis, we examine whether evidence for the separate subsystems hypothesis is obtained in a standard identification task when words *and* pseudowords are identified. A RH advantage for case-specific priming is not found in this experiment, failing to support the specialized word subsystem explanation.[5] Therefore, in Experiment 2, we hypothesize

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[5] The results from Experiment 1 are important also for ruling out other possible explanations for the discrepant priming results between earlier priming studies. The results from Experiment 1 replicate findings from the earlier perceptual identification experiment (Koivisto, 1995) despite many methodological differences between the two. Comparing Koivisto's experiment and Experiment 1 in this article, differences include the font for test stimuli (unfamiliar shadow font vs relatively familiar Helvetica font), the proportion of female to male subjects (39:9 vs 16:16), exposure durations of test items (calibrated for each subject [ranging from 160 to 190 ms] vs 17 ms for all subjects), language (Finnish vs English), case of test items (all lowercase vs half uppercase and half lowercase), frequency of words in the language (medium frequency vs low frequency), and method of response (spoken vs written). Given that we replicate Koivisto's results in Experiment 1, and given that Experiment 2 was conducted similarly to Experiment 1, the various methodological differences between Koivisto's and our experiments are not as important as the difference in task demands between our Experiments 1 and 2 for determining whether an SVF subsystem will contribute substantially to priming.

that the task demands in the standard perceptual identification task produce a situation in which an SVF subsystem does not contribute strongly to priming and that an SVF subsystem may contribute strongly to priming in an identification task when the demands are modified so that case-specific information is necessary for accurate performance. To test this hypothesis, we examine whether evidence for the separate subsystems hypothesis is obtained in a form-specific identification task, in which subjects identify the letter case of test strings as well as the strings themselves. A RH advantage for case-specific priming is obtained in this experiment. Thus, we conclude that an SVF subsystem, but not an AVF subsystem, operates more effectively in the RH than in the LH.

In both Experiments 1 and 2, items presented directly to the LH are identified more accurately than items presented directly to the RH. This result is consistent with previous findings (Beaumont, 1982; Mishkin & Forgays, 1952; Young et al., 1984). It should be noted that, even though a LH advantage for word and pseudoword identification produces an asymmetry in baseline identification performance, this asymmetry likely does not compromise our conclusions regarding priming. It is present in Experiment 2, when we find an asymmetry in priming effects, as well as in Experiment 1, when we do not. Likewise, ceiling effects probably do not compromise our conclusions. Identification rates are generally high (although not greater than 85%). Yet, this is true in Experiment 2, when we find an asymmetry in priming effects, as well as in Experiment 1, when we do not.

The results from these experiments illustrate the crucial role of task demands in determining the relative contributions of AVF and SVF subsystems to priming in different visual tasks. In the standard identification task (Experiment 1; Koivisto, 1995), an AVF subsystem may be very efficient for accomplishing the goal of reporting the one correct letter string per trial, and contributions from an SVF subsystem are not necessary for accurate performance. Therefore, an AVF subsystem may support the majority of visual priming during that task. However, in the form-specific identification task (Experiment 2), contributions from an SVF subsystem are essential for accurate performance, and therefore, both AVF and SVF subsystems may be recruited to accomplish the task. By modifying the demands of the standard identification task, we create a situation similar to that of stem completion, in which more than one subsystem may contribute substantially to visual priming. Because word-stem completion tasks are less constrained than perceptual identification tasks, many different subsystems may be recruited to underlie performance and the task demands need not be modified to test properties of both AVF and SVF subsystems. However, in order to test properties of AVF and SVF subsystems in a perceptual identification task, the task demands may need to be modified so that both AVF and SVF subsystems contribute substantially to performance.

Other interesting differences between the findings of Experiments 1 and

2 are the following. First, in Experiment 2, but not in Experiment 1, uppercase items are identified more accurately than lowercase items, and this advantage is greater for items presented directly to the RH than for those presented directly to the LH (albeit in a marginally significant interaction effect). This difference may be explained in terms of the change in task demands across the two experiments. In Experiment 1, there was no difference in accuracy between lower- and uppercase items probably because case information did not need to be processed for accurate performance. However, in Experiment 2, there was a difference in accuracy between lower- and uppercase items probably because case information was required for accurate performance. The reason uppercase letters are identified more accurately than lowercase items may be due to stimulus differences that would become important when the identification task is form-specific. Uppercase letters are larger and hence may be easier to visually identify than lowercase letters, they are less common in everyday use and hence may be less susceptible to proactive interference (produced by preexperimental processing of words or letters that could adversely affect processing of those words or letters during the experiment) than lowercase letters, and they are composed of relatively simple straight-lined structures and hence may be easier to process in very brief viewing conditions than lowercase letters. Of course, a parametric study of these factors would be needed to determine the crucial variable(s). Moreover, the greater uppercase advantage in RH presentations than in LH presentations in Experiment 2 suggests that subsystems that operate more effectively in the RH than in the LH may be especially sensitive to these factors of size, familiarity, or structural complexity.

Other differences in findings between Experiments 1 and 2 may help to clarify which subsystems are involved in pseudoword priming. Bowers (1996) suggests that priming for pseudowords is not supported by a specialized word-form subsystem, but rather by nonspecialized subsystems that process relatively specific form information, such as letter case. Results from Experiment 1 support this hypothesis. Primed same-case pseudowords are identified more accurately than primed different-case pseudowords, and this case effect is not obtained for words. However, results from Experiment 2 do not support this hypothesis. Pseudowords and words are not identified differentially depending on whether they were primed in the same or different letter case compared with test items. We suggest that the same subsystems are capable of supporting priming for pseudowords and priming for words, but with interesting differences in which subsystems may come into play in different experiments, as suggested below.

We suspect that the results from Experiment 2 are more informative about the properties of visual form subsystems than the results from Experiment 1, because processing of form-specific visual information is required in Experiment 2 but not in Experiment 1. Accordingly, the greater case-specific priming for pseudowords than words in Experiment 1 may be due to storage of information about pseudowords in conceptual/associative subsystems. These subsystems presumably are able to represent the conceptual fact of the matter that a certain letter string can be composed of lowercase letters or uppercase letters, via a conceptual description of such information (residing in association cortex) rather than a visual representation per se (residing in visual cortex). Such conceptual/associative storage is more likely to play a role in pseudoword priming than in word priming. Words have well-established representations in visual-form subsystems that influence priming before conceptual/associative processing is performed. Hence, visual-form representations dominate the observed priming for words. Pseudowords, however, do not have well-established visual-form representations to influence priming early in processing, only recently created visual-form representations that may be less able to support priming than the well-established visual-form representations for words. Hence, newly created representations in conceptual/associative subsystems may contribute to pseudoword priming to a greater degree than word priming. Moreover, newly created representations in conceptual/associative subsystems should play a significant role in the case-specific pseudoword priming in Experiment 1.

Furthermore, the reason that there is no greater case-specific priming for pseudowords than words in Experiment 2 is likely because newly created representations in conceptual/associative subsystems should play less of a role in pseudoword priming in Experiment 2 than in Experiment 1. The form-specific nature of the task in Experiment 2 may constrain subjects to retrieve only visual information and not conceptual/associative information. Consistent with this explanation, in Experiment 1 but not in Experiment 2, the LH advantage for identifying pseudowords is greater than the LH advantage for identifying words. This suggests that much of the priming of pseudowords in Experiment 1 was not supported by an SVF subsystem, but rather, may have been mediated by other (conceptual/associative) subsystems. These explanations are admittedly speculative, however, and further research is needed to shed more light on these issues.

To conclude, visual-form recognition appears to be supported by two relatively independent subsystems. An SVF subsystem, but not an AVF subsystem, operates more effectively in the RH than in the LH and supports priming for specific instances of form (e.g., lower- vs uppercase versions of the same letter string). Support for this hypothesis is obtained with a form-specific perceptual identification task, but not with a standard perceptual identification task, indicating that task demands play a crucial role in determining the relative contributions of AVF and SVF subsystems in different priming tests. Careful task analyses appear to be needed when hypothesizing how different processing subsystems conspire to subserve task performance in priming experiments. These conclusions highlight an important aspect of the componential approach to investigating the cognitive neuroscience of visual-form processing.

APPENDIX

Letter Strings Used in Both Experiments

Words	Pseudo-words	Words	Pseudo-words	Words	Pseudo-words	Words	Pseudo-words
HYENA	LYENA	GASH	GATH	DEITY	BEITY	TINT	TIRT
STUNT	SPUNT	PLUM	CLUM	BLOKE	BLOGE	FRET	GRET
FRIAR	TRIAR	DUET	DUEK	SPILL	SNILL	FROG	KROG
MURAL	BURAL	JADE	JABE	FLAKE	FRAKE	FERN	FERD
FLUTE	FLUPE	SURF	MURF	CLANG	CRANG	GUNK	ZUNK
TOXIN	TOXIT	MUFF	SUFF	JEWEL	JEMEL	HASH	KASH
LADLE	LAGLE	POMP	POLP	AXIOM	AXIOD	CLAW	CLAT
PRUNE	PRUTE	VEAL	VEAM	FORAY	FOWAY	GRIT	TRIT
TUNIC	TUVIC	WEED	ZEED	CLOUT	CLOUP	BOAR	NOAR
GHOUL	GHOUT	MITE	JITE	AMITY	AWITY	BRAN	BRAP
GORGE	DORGE	DRIP	BRIP	BRAWL	GRAWL	CUBE	CUNE
CADDY	YADDY	GURU	GULU	GUILE	GUINE	PERK	NERK
VIGIL	DIGIL	HOBO	NOBO	CAMEL	BAMEL	MUCK	JUCK
CACHE	CATHE	GULL	KULL	FAUNA	RAUNA	DIVA	DIBA
TRAMP	DRAMP	DUNE	DUTE	CRANK	WRANK	FLOP	FROP
HOIST	HOINT	RUNT	RUND	BISON	LISON	LAVA	RAVA
CRYPT	GRYPT	YOGA	YOMA	BONGO	BONTO	FOWL	KOWL
SKATE	SNATE	FAWN	FAWD	RODEO	ROVEO	CUFF	CUFT
URINE	UTINE	FIFE	FIME	SPOUT	SPOUD	GIST	GISP
KIOSK	FIOSK	SHAM	THAM	ROOST	ROOSH	NOUN	GOUN
PRANK	PRANT	FEUD	LEUD	BRUNT	KRUNT	SKIT	STIT
NYLON	NYDON	SOOT	WOOT	MAMBO	MALBO	RASH	RACH
SNAIL	PRAIL	RIFT	RINT	ETHER	ETHET	LOIN	LOID
SQUAW	SQUAM	JOCK	TOCK	BLIMP	GLIMP	PUFF	WUFF
BELLE	PELLE	PEAL	JEAL	WHACK	WHALK	CLOD	CROD
BRIAR	BRIAL	HOPS	GOPS	CHIVE	SHIVE	JINX	TINX
TRIAD	THIAD	MALT	VALT	ICING	IBING	CASK	FASK
BINGE	VINGE	MASH	PASH	CRUST	CRUSK	DUNK	TUNK
FELON	TELON	HARP	HARN	CLOVE	PLOVE	IOTA	IOGA
SHRUB	SHRUD	THUG	THUT	BOXER	NOXER	NOVA	DOVA
ROGUE	KOGUE	WAND	GAND	BRIBE	PRIPE	MOTH	MOCH
INSET	INSED	CZAR	CZAT	OMEGA	OMETA	FRAY	GLAY

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