Available online at www.sciencedirect.com
SCIENCE DIRECT®

Brain and Language 95 (2005) 414–422

Brain and Language

www.elsevier.com/locate/b&l

Masked priming is abstract in the left and right visual fields ☆

Jeffrey S. Bowers *, Emma L. Turner

Department of Experimental Psychology, University of Bristol, Clifton, Bristol, BS8-1TN, UK

Accepted 14 March 2005
Available online 24 May 2005

Abstract

Two experiments assessed masked priming for words presented to the left and right visual fields in a lexical decision task. In both Experiments, the same magnitude and pattern of priming was obtained for visually similar (*kiss-KISS*) and dissimilar (*read-READ*) prime–target pairs. These findings provide no support for the hypothesis that word identification is mediated by separate and lateralized abstract and specific visual form systems. Strikingly, equivalent priming was observed when primes and targets were presented to the same or opposite visual fields, suggesting that priming occurs after visual information from the two hemispheres is integrated.

Keywords: Lexical decision; Word identification; Reading; Hemisphere; Lateralization

1. Introduction

A fundamental question for theories of perception and memory is how to identify and retrieve information at different levels of abstraction. In the case of visual perception, the system(s) must recognize that different items belong to the same abstract category when they are functionally equivalent (e.g., selecting a random hat from a set of different hats) and belong to different categories when items are functionally distinct (e.g., selecting "my" hat amongst many).

Many theories of pattern recognition ignore these two different requirements, and instead focus on accomplishing only one of these goals. For example, to recognize objects at a basic level, Biederman (1987) argues that objects are represented in terms of "structural descriptions" specifying an object's parts in terms of categorical 3D shape primitives (e.g., brick, cones, etc.) and their categorical relations to one another (e.g., on-top-of). So on this account, a table might be represented as a horizontal slab on top of four vertical posts. The abstract nature of these representations allows the model to categorize familiar and novel objects at a basic level since members of the category typically share the same description—i.e., most tables will be represented as a horizontal slab on top of four vertical posts, regardless of viewing angle. But the categorical nature of these representations leads to problems when trying to distinguish between two different tables that share the same structural description.

By contrast, "view based" models represent objects as holistic two-dimensional patterns as they appear from specific views, and identification consists in comparing holistic visual input patterns to these holistic memory representations. Because these visual codes encode the precise metrical information of the 2D views, view based models show promise in explaining exemplar-specific object recognition (i.e., recognizing the same objects from different viewpoints), but relatively little work has

☆ We thank Marc Brysbaert, Max Coltheart, Ken Forster, Andy Ellis, Chad Marsolek, Christine Mohr, Martin Pickering, and Padraic Monaghan for helpful comments on earlier drafts of this article.
* Corresponding author. Fax: +011 44 117 928 8588.
E-mail addresses: j.bowers@bris.ac.uk (J.S. Bowers), Emma.turner@bris.ac.uk (E.L. Turner).

0093-934X/$ - see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandl.2005.03.004

addressed the question as to whether these models can accommodate basic level recognition (cf. Hummel & Stankiewicz, 1998; Tarr & Gauthier, 1998).

A similar issue arises in the case of visual word identification where words can be depicted in different fonts, handwriting style, case, etc. On the one hand, various forms of evidence suggest that different instances of a given word map onto abstract word representations, even when the instances are visually dissimilar (e.g., *READ*/*read*; for review, see Bowers, 2000). On the other hand, readers maintain the ability to distinguish words written in different visual formats, and these differences can serve important functional roles (e.g., identifying a person's handwriting, or emphasis—STOP). As is the case with models of object identification, models of word identification that incorporate abstract word representations do not provide an obvious means for distinguishing between different instances of a given word, whereas models that represent words as collection of instances in memory (e.g., Hintzman, 1986) do not provide an obvious account of how visually dissimilar exemplars of a given word are mapped onto common orthographic representations (cf. Bowers & Michita, 1998).

Recently, a number of theorists have argued that the complementary successes of "abstract" and "instance" approaches are not accidental, but rather, reflect a basic functional constraint; namely, the set of processes that support the effective categorization of items into basic level categories (i.e., identifying the invariant features across instances) are incompatible with the goal of distinguishing different exemplars of the same category (identifying the specific perceptual information that distinguishes instances). Accordingly, it has been argued that different systems support these two functions, an abstract visual form (AVF) and a specific visual form (SVF) system (e.g; Marsolek, Kosslyn, & Squire, 1992; for a related argument, see Farah, 1990). This approach is at odds with the more standard view that common systems support abstract and specific categorizations (e.g., Knapp & Anderson, 1984; McClelland & Rumelhart, 1985; Tarr, 1995).

The most explicit version of this hypothesis has been put forward by Marsolek and colleagues who argue that two relatively independent subsystems support our ability to categorize inputs at a general and specific level, and these subsystems operate more effectively in the left and right hemispheres, respectively. According to this view, the visual features common to most members of a general category are found in the parts of the larger whole, and thus the AVF system is designed to identify objects by identifying their parts. By contrast, the visual features distinguishing instances within a category are generally found in the wholes of the forms, thus the SVF is designed more in line with the "view specific" approach. For purposes of this discussion, this view will be labeled the two-systems hypothesis.

The strongest support for this view has been reported in a series of studies employing the long-term priming paradigm. Long-term priming refers to a facilitation or bias in processing a stimulus as a consequence of having encountered the same or a related stimulus in an earlier episode. For example, in the stem-completion task, participants are more likely to complete a word stem (e.g., TAB____) as TABLE if TABLE was studied a few minutes earlier. Using the stem-completion task, Marsolek and colleagues (e.g., Marsolek et al., 1992; Marsolek, Squire, Kosslyn, & Lulenski, 1994) have found that long-term priming for words is insensitive to study-to-test changes in letter-case when stems are flashed to the right visual field and sensitive to these changes when stems are flashed to the left visual-field, suggesting that the word representations that mediate priming (and word identification) are abstract and visually specific in the left and right hemispheres, respectively. Marsolek (1999) obtained a similar pattern of priming for objects using a perceptual identification task, with equivalent same exemplar and different exemplar priming when targets were flashed to the right visual field, and greater same compared to different exemplar priming when targets were flashed to left visual field.

It should also be noted that the postulation of lateralized abstract and specific perceptual systems is compatible with a variety of nonpriming results as well. For example, with written materials, Geffen, Bradshaw, and Nettleton (1972) reported a left hemisphere advantage for matching upper- and lower-case letters (e.g., A/a = yes) and a right hemisphere advantage for making physical matches (e.g., A/A = yes). Similarly, Gibson, Dimond, and Gazzaniga (1972) and Hellige (1980) provided evidence that visual short-term memory for letters and words was mediated by relatively abstract and specific representations in the left and right hemispheres, respectively (although the results with letters have been mixed, e.g., Segalowitz & Stewart, 1979). Employing fMRI, Polk and Farah (2002) reported left but not right hemisphere activation in the word-form area for case aLtErNaTiNg words and nonwords.

Although these nonpriming results support the conclusion that abstract and specific perceptual systems are lateralized to the left and right hemispheres, we would emphasize that these findings do not speak directly to the two-systems hypothesis. A number of these studies do support the claim that visual word identification are supported by abstract perceptual systems lateralized to the left hemisphere, but this is a familiar claim adopted by most theorists (e.g., Coltheart, 1981; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002; Polk & Farah, 2002). The novel claim is that parallel specific perceptual systems lateralized to the right hemisphere also contribute to the identification of words (and objects). The observation that font identification, visual matching, etc. are all better performed in the right hemisphere is not relevant to this claim, as they do not constitute examples of letter or word identification.

Accordingly, the long-term priming studies reported by Marsolek and colleagues provide the main source of evidence that visual word and object identification is supported by parallel and lateralized AVF and SVF systems. And within this restricted domain, the key evidence in support of the two-systems hypothesis for words has been obtained using the stem-completion task—a task that is only indirectly related to the process of identifying words (the task measures word generation, not word identification). And even here, the priming results only support this hypothesis under a restricted set of conditions, for example, when the word stems allow multiple completions, but not single completions (Marsolek & Hudson, 1999). These qualifications weaken the case for the two-systems view, and to provide more direct support for this hypothesis, data from other tasks, particularly from tasks that directly assess word and object identification, are required.

However, the few relevant studies that have assessed the identification of words and objects also provide mixed support for the two-systems hypothesis. For example, Bryden and Allard (1976) reported a study that contrasted the identification of single letters presented to the left and right visual fields. The authors reported a left visual field advantage for identifying letters presented in unusual fonts (that were relatively difficult to identify) and a right visual field advantage for letters presented in more familiar format (and more easily identified). This is problematic because the identification of letters printed in unusual format requires a greater degree of generalization to be identified (the letters in a given font were only presented once in the left and right visual fields in Experiment 1), and accordingly, a left hemisphere advantage might have been expected.

Koivisto (1995) observed that long-term priming for words is insensitive to study-to-test changes in letter case when targets were flashed in the left or right visual field in a perceptual identification task (a task that assesses word identification more directly than the stem-completion task). On the two systems view, it might have been expected that case changes would reduce priming when targets were flashed in the left visual field. In response to these findings Burgund and Marsolek (1997) argued that the perceptual identification task is poorly suited to assess the functioning of the SVF, and introduced a form-specific identification task in which participants were asked to identify both the identity and the letter case of the flashed items. In this condition the authors did obtain more case-specific priming in the left visual field in one study, which the authors interpreted in support for the two-systems hypothesis. Similarly, mixed results have been obtained when priming for objects has been assessed in a perceptual identification task. For instance, both Biederman and Cooper (1991) and Marsolek (1999) found greater priming when the same pictures were repeated at study and test compared to a condition in which different exemplars were repeated (e.g., different pictures of a chair), and the advantage was equally large when test items were flashed to the left or right visual fields. However, Marsolek (1999) attributed these findings to the fact that the pictures were only presented relatively briefly at study (e.g., 500 ms in the Marsolek study), and argued that these conditions may have degraded the initial encoding of the items, which may in turn have impaired the functioning of the AVF in the left hemisphere. When the study was repeated with pictures presented for 3 s, priming was abstract when targets were flashed to the right visual field and specific when flashed to the left.

Given the importance of this issue and the limited conditions in which the two-systems hypothesis has been supported, we decided to study this issue further, focusing on written words. We tested the two-systems hypothesis using a task that has been widely used to study word identification, namely, the masked lexical decision task. In this procedure, a mask (e.g., ####) precedes a lower-case prime (e.g., *read*) presented for a brief duration (e.g., 60 ms), which in turn is a followed by an upper-case target (e.g., *READ*) to which the participant must respond by categorizing the target as a word or nonword. The prime duration is sufficiently short that participants are generally unaware of its existence, and nevertheless, response times to targets are reduced when they are preceded by a related compared to unrelated prime (Bowers, Vigliocco, & Haan, 1998; Forster & Davis, 1984). Critical for present purposes, no correlation has been found between the size priming and the visual similarity of the primes and targets in lower- and upper-case, suggesting that the orthographic codes that support priming are visually abstract (e.g., Evett & Humphreys, 1981; Humphreys, Besner, & Quinlan, 1988; for a related finding, see Davis & Forster, 1994). More recently, Bowers et al. (1998) contrasted masked priming for a set of words that are visually similar (e.g., *kiss*/*KISS*) and dissimilar (e.g., *edge*/*EDGE*) in their lower- and upper-case forms. No effect of this manipulation (not even a trend) was found in a lexical decision or a verb/noun categorization task, and only a small effect arose in a perceptual identification task in which the targets were degraded. These findings parallel long-term priming results obtained with perceptual identification (e.g., Bowers, 1996), lexical decision (e.g., Bowers & Michita, 1998), and stem- and fragment-completion (e.g., Rajaram & Roediger, 1993) tasks.

These masked (and long-term) priming results were all obtained when words were presented to the center of fixation, but if a SVF lateralized to the right hemisphere contributes to identification, then cross-case masked priming should be sensitive to the degree of prime–target visual overlap when the items are presented to the left visual field, consistent with various "view" or "instance" based theories of priming (cf., Tenpenny, 1995), and consistent with the long-term stem-completion priming results reported by Marsolek and colleagues. Priming in the left hemisphere, by contrast, should be insensitive to these visual factors.

To test this prediction we assessed masked priming for visually similar (e.g., *kiss/KISS*) and dissimilar (e.g., *edge/EDGE*) prime–target pairs when the primes and targets were lateralised to either left or right visual field. The critical prediction is with regards to the relative impact of the visual similarity manipulation in the two hemispheres. On the two systems view, visual similarity should have a larger impact in the RH compared to the LF, such that any reduction in priming for the dissimilar compared to the similar items should be larger when the primes and targets are both flashed to the LVF (RH) compared to RVF (LH).

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four right-handed students (12 men and 12 women) were included in Experiment 1. All were from the University of Bristol and participated in return for course credits or payment of £3 for 30 min. Participants were all tested individually.

2.1.2. Design and materials

Experiment 1 included three within participants factors: (a) visual field of the prime–target pairs (left–left vs. right–right), (b) prime–target similarity (visually similar vs. dissimilar), and (c) priming condition (repeated vs. nonbaseline). Twelve four-letter words were selected, with six visually similar items (*soon*-*SOON*, *stop*-*STOP*, *post*-*POST*, *cost*-*COST*, *ship*-*SHIP*, *wish*-*WISH*) and six visually dissimilar (*able*-*ABLE*, *edge*-*EDGE*, *read*-*READ*, *data*-*DATA*, *ball*-*BALL*, *game*-*GAME*). These items were categorized as similar or dissimilar based on judged similarity norms in which upper- and lower-case letters were coded on a 5 point scale (Boles & Clifford, 1989). Averaging over letters in a word, the judged similarity of the similar (3.85) compared to dissimilar (2.49) words was highly significant, $p < .01$, and this contrast has been shown to affect performance on a number of tasks, including letter matching (Nicholas & Marsolek, 1996) and long-term priming (Bowers, 1996). In the repeated condition the same words were repeated (e.g., *soon*-*SOON*), whereas in the baseline condition, similar (e.g., *soon*-*POST*) and dissimilar (e.g., *able*-*EDGE*) items were randomly paired with each other. A set of six visually similar (e.g., *pisk*-*PISK*) and six dissimilar (e.g., *beld*-*BELD*) pseudowords served as nonword foils in the lexical decision task. Each target item was repeated twice in each condition, making a total of eight repetitions. Including the 24 practice trials the subjects performed 216 lexical decisions. The words were all high frequency (mean frequency of the visually similar words was 138 and the visually dissimilar was 146; Kucera & Francis, 1967), which reduces or eliminates the role of phonological processing in cross-case priming in the lexical decision task (Bowers et al., 1998).

2.1.3. Procedure

The experiment was run on a Pentium computer with items presented in black 10 point Courier New font on a white background using the DMASTER display software developed at the University of Arizona by K.I. Forster & J.C. Forster. The participants were all approximately 50 cm from the screen with their chin supported by a chin rest. Participants were instructed to attend to the central fixation point and make lexical decisions to the upper-case targets as quickly and accurately as possible. The central fixation cross appeared for 400 ms followed by two masks (####) with their inner edge 2.25 cm to the left and right of fixation (approximately 2.5° from fixation), and these were presented for 15 ms after which one mask was replaced by the prime for 60 ms, followed by the target presented in the same location as the prime for another for 500 ms (the mask in the other visual field remained on the screen until the target was removed). All primes were presented in lower-case and all targets in upper-case. It is important to note that re-fixations from one target to another take approximately 200–300 ms, and even when uncertainty about when or where to move the eyes is eliminated, saccade latency is at least 150–175 ms (Rayner & Sereno, 1994); accordingly, the 60 ms primes were lateralized to one visual field for their duration. Although less important for present purposes, the targets were also initially lateralized until participants fixated on them.

Participants pressed the right shift key for words and left shift-key for nonwords and completed a number of practice trials before commencing the critical trials. Feedback concerning accuracy and response latencies were given in both practice and test trials.

2.1.4. Results

Participants whose overall error rate exceeded 20 percent were rejected from the Experiments 1 and 2; no participants were dropped based on this criterion in Experiment 1. In addition, reaction times (RTs) more than two standard deviation units above or below the overall mean for a given participant in a given condition were also thrown out. This constituted 4.3% of the trials for the present experiment.

Table 1
Response latencies (ms) and error rates (%) in Experiments 1 as a function of prime condition, prime–target visual field, and word type

Word type	Conditions	Experiment 1a visual field of prime and target	
		Left–Left	Right–Right
Similar			
	Rep	581 (3.5)	561 (2.4)
	Base	616 (4.5)	604 (3.5)
	Priming	35 (1)	43 (1.1)
Dissimilar			
	Rep	599 (5.2)	567 (2.1)
	Base	637 (6.9)	597 (4.9)
	Priming	38 (1.7)	30 (2.8)

Error rates in parentheses.

The response latencies and error rates for words in Experiment 1 are presented in Table 1.[1] An overall ANOVA carried out on the response latencies revealed a main effect of visual field, $F(1,23) = 17.11$, $MSe = 1899$, $p < .01$, with a reduced latency to respond to words presented to the right (582 ms) compared to the left (608 ms) visual field. That is, the standard laterality effect was obtained. In addition, a main effect of word type was obtained, $F(1,23) = 6.62$, $MSe = 597$, $p < .05$, reflecting the reduced latencies to respond to visually similar (590 ms) compared to dissimilar (599 ms) words. There was also a large (37 ms) priming effect, $F(1,23) = 108.55$, $MSe = 593$, $p < .01$, reflecting the faster responses in the repeated compared to the corresponding baseline conditions. The analysis of the error data only revealed a significant main effect of visual field, with fewer errors in the right (3.2%) compared to left (5.0%) visual field, $F(1,23) = 4.88$, $MSe = 32.6$, $p < .05$.

An ANOVA carried out on the RT and error priming scores (baseline performance minus repeated performance) failed to obtain any effects, indicating that a similar amount of priming was obtained across all visual field conditions. The equivalent priming for similar and dissimilar prime–target pairs in the two hemispheres poses a direct challenge to the two systems hypothesis: if word knowledge is coded in a visually specific format in the right hemisphere, priming should have been reduced for the dissimilar prime–target pairs presented in the left visual field.

[1] Responses to nonwords targets in the lexical decision task are difficult to interpret because there are conflicting processes at work: repeating the prime and target facilitates the perception of the target, but the associated processing fluency of the primed targets results in a bias to respond YES these nonwords (e.g., Bodner & Masson, 1997). One consequence of this bias is that nonword priming tends to be reduced or eliminated in the lexical decision task (although not in other tasks). Accordingly, only the words were analyzed in the present studies.

3. Experiment 2

The parallel priming effects obtained for the similar and dissimilar words poses a challenge for the two systems hypothesis. However, before making any strong conclusions, our failure to obtain the predicted interaction between visual field and word type (a null effect) warrants replication. It is important to note that this null effect cannot be attributed to a general insensitivity of the masked priming experiment, as both robust laterality and priming effects were obtained. Furthermore, the robust priming for dissimilar words presented to the left visual field poses a challenge to the two systems hypothesis. Nevertheless, we carried out a second experiment to replicate the above finding. Experiment 2 was similar to Experiment 1 except that the primes and targets were presented in opposite visual fields on half of the trials. The critical question is whether the same pattern of priming is obtained when the prime–target pairs are presented in the left–left and right–right visual field conditions (as in Experiment 1) when the location of the prime is no longer predictive of the location of the target.

3.1. Method

3.1.1. Participants

Another group of 32 right-handed students (16 men and 16 women) from the University of Bristol and participated in return for course credits or payment of £3 for 30 min. Participants were given a shortened version (eight questions) of the Edinburgh Handedness Inventory (Oldfield, 1971) that assesses degree of handedness (questions such as: Which hand do you prefer when you: write, draw, throw, strike a match, etc.), and responded right 7.8/8 on average.

3.1.2. Design and materials

Experiment 2 differed from Experiment 1 with regards to the location of the primes and targets: here, the primes and targets were presented equally often in all visual field conditions (left–left, left–right, right-left, right-right) making the location of the target unpredictable given the location of the prime. The same set of words were used in the present experiment, but pseudoword foils in Experiment 1 were replaced with a set of six visually similar (waik-WAIK) and dissimilar (e.g., *dert-DERT*) pseudohomophones. The pseudohomophone foils were included in an attempt to reduce any phonological priming in the lexical decision task (e.g., Grainger & Ferrand, 1994; but see Pexman, Lupker, & Jared, 2001). The nonwords were organized into the repeated and baseline conditions in the same way as the words. Each target item was repeated twice in each condition, making a total of 16 repetitions. Including 24 practice trials the subjects performed 408 lexical decisions.

3.1.3. Procedure

The procedure was the same as in Experiment 1 except that the word–nonword response mappings were varied between participants. Half of the participants were instructed to press the right shift key for words and the left shift key for nonwords, and for the other participants, the mappings were reversed.

3.1.4. Results

Two participants who made more than 20% errors were dropped from the analysis and replaced. In addition, RT trials two standard deviation units above or below the overall mean for a given participant in a given condition (4.0% of trials).

The response latencies and error rates of Experiment 2 are presented in Table 2. The overall ANOVA carried out on the RT data revealed a large effect of visual field, $F(3,93) = 21.9$, $MSe = 6036$, $p < .01$, reflecting the faster responses when primes and targets were presented to the same (581 ms) compared to different (635 ms) visual field. This within visual field advantage was equivalent in the repeated and baseline conditions, consistent with an attention orienting effect, as will be discussed in Section 4. In addition, consistent with Experiment 1, a main effect of word type was observed, $F(1,31) = 6.34$, $MSe = 1869$, $p < .05$, reflecting the faster responses to the visually similar (603 ms) compared to dissimilar (613 ms) targets words. Finally, a priming effect of 48 ms was highly significant, $F(1,31) = 73.82$, $MSe = 3976$, $p < .01$. In terms of errors, the overall ANOVA revealed a main effect of visual field, $F(3,90) = 2.86$, $MSe = 89.98$, $p < .05$, with slightly elevated errors in the left-right visual field condition.

An ANOVA carried out on the priming scores revealed a main effect of visual field, reflecting the reduced priming when primes were presented to the left (37 ms) compared to the right (59 ms) visual field, $F(3,90) = 4.76$, $MSe = 2194$, $p < .01$. This finding suggests that priming is greatest when primes are directly projected to the left hemisphere that normally subserves reading (e.g., Polk & Farah, 2002). Note, this finding contrasts with the similar priming obtained for primes presented to the left and right visual fields in Experiment 1. The reason for this discrepancy is unclear. In any case, the critical finding is that the same pattern of priming was obtained for the visually similar and dissimilar prime–target pairs across the visual field conditions, $F(3,90) < 1$, indicating that this laterality difference in priming does not reflect any differences in the processing of abstract and specific visual knowledge in the two hemispheres. Thus the present findings again pose a challenge to the two systems hypothesis.

Table 2
Response latencies (ms) and error rates (%) in Experiment 2 as a function of prime condition, prime–target visual field, and word type

Word type	Conditions	Visual field of prime and target			
		Left–Left	Right–Right	Left–Right	Right–Left
Similar					
	Rep	558 (6.8)	544 (3.6)	616 (8.1)	596 (4.7)
	Base	596 (6.5)	598 (5.5)	655 (7.6)	663 (7.0)
	Priming	38 (−0.3)	54 (1.8)	38 (−0.5)	67 (2.3)
Dissimilar					
	Rep	569 (6.5)	560 (5.5)	638 (9.1)	592 (4.2)
	Base	607 (7.0)	617 (3.9)	672 (7.3)	650 (7.8)
	Priming	38 (0.5)	56 (−1.6)	34 (−1.8)	57 (3.7)

Error rates in parentheses.

Perhaps the most striking finding is that we observed equivalent priming when prime targets were presented to the same (47 ms) and different (49 ms) visual fields. This provides an interesting contrast to the finding that RTs were faster when prime–target pairs were presented to the same compared to different hemisphere. The implication of this later finding is discussed below.

4. General discussion

Two key result are reported in the present paper: (a) robust cross-case masked priming was obtained for visually dissimilar (*read/READ*) prime–target pairs presented to the left visual field, and (b) parallel priming effects were obtained for the dissimilar and similar prime–target pairs across all visual field conditions. Accordingly, no support was obtained for the two-systems hypothesis according to which visual word identification is mediated by abstract visual form (AVF) and specific visual form (SVF) systems lateralized to the left and right hemispheres, respectively. On this hypothesis, cross-case priming should be reduced for the dissimilar prime–target pairs presented to the left visual field.

In addition to posing a challenge for this AVF/SVF distinction, the present findings address a number of related issues. A surprising result (at least to us) was that priming was equivalent when the prime–target pairs were presented to the same or different hemispheres in Experiment 2. This suggests that the processes that support masked priming occur late, after information about the prime and target are transferred to a common hemisphere—presumably an abstract system given the nature of the priming effects. One interpretation of the present finding is that perceptual analyses carried out on the prime within the right hemisphere were quickly transferred to the left hemisphere, and that the abstract orthographic representations within the left hemisphere (e.g., Polk & Farah, 2002) mediated the masked priming effects. On this account, there was no role for specific representations in masked priming, and no evidence that a SVF system within the RH contributes to word identification.

Although the equivalent within- and cross-hemisphere priming was unexpected, it makes sense in light of evidence that visual information projected onto the fovea is strongly lateralized, with bilateral projections from the fovea to visual cortex highly restricted (cf. Brysbaert, 2004). For example, anatomical studies on the macaque show that visual information projected 0.15° away from the vertical meridian are unilaterally projected to the contralateral hemisphere (Tootell, Switkes, Silverman, & Hamilton, 1988). In addition, Fendrich, Wessinger, and Gazzaniga (1996) found that the split-brain patient V.P. could not compare two small shapes presented 0.25° on either side of the vertical meridian. The implication is that the beginnings of centrally fixated words are projected to the RH and the ends of words are projected to the LH, with integration of information from the two hemispheres required before word identification can be achieved. The fact that word identification typically requires integrating information from both hemispheres helps explain the robust cross-hemisphere priming results observed here (for related cross-hemisphere priming results, see Ratinckx & Brysbaert, 2002).

It is interesting to note that Marsolek and colleagues have not taken this anatomical constraint into consideration when developing the two-system hypothesis; the implicit assumption has been that information projected onto the fovea is bilaterally projected, with the two hemispheres processing complete words in either an abstract (LH) or specific (RH) manner. By contrast, a number of recent theories of word identification have taken the "split-fovea" into account, with the two hemispheres dealing with the beginnings and endings of words in different ways (Ellis, 2004; Shillcock, Ellison, & Monaghan, 2000; Whitney, 2001). Although these latter theories differ in some important respects, none of them assume that written word identification is mediated by visually specific word representations in the right hemisphere. Indeed, Ellis, Brooks, and Lavidor (in press) explicitly argue that the letters are coded in an abstract format in the right hemisphere, and Ellis (2004) argues that only the left hemisphere includes both specific and abstract letter representations involved in word identification (just the opposite of the claim of Marsolek and colleagues). The present finding can be reconciled with these latter approaches given that they allow for abstract orthographic knowledge in both hemispheres, and only poses a challenge for the two-systems account according to which visually specific representations (of complete words) mediates word identification in the RH.

Another point to make about the equivalent within and between hemispheres priming in Experiment 2 is that this occurred at the same time that RTs were reduced when primes and targets were presented to the same hemisphere. That is, in addition to the impact of the prime–target identity, the location of the prime relative to the target also affected performance. We would suggest that this within visual field advantage reflects an attentional orienting effect (e.g., Posner, 1980), with the location of the prime capturing spatial attention, which in turn supported faster responding to targets at the same location. This is interesting in its own right given that the positional cue (the prime) was flashed for 60 ms and masked—conditions that make the prime difficult to perceive (for another example of a masked prime supporting an attentional orienting effect, see Neumann, Esselmann, & Klotz, 1993; Scharlau & Neumann, 2003). But more relevant to present purposes, the fact that masked priming was equivalent within and between hemispheres suggests that priming is relatively insensitive to attentional manipulations that affect the processing of the *target*. That is, even though attention was temporarily directed away from the target when prime–targets were presented in the opposite visual fields, priming was unaffected. This contrasts to cases in which attention is directed away from the masked prime, which eliminate priming (Lachter, Forster & Ruthruff, 2004).

One possible concern with the current masked priming studies is that the same primes and targets were repeated numerous times for each subject, unlike the more common procedure of presenting each prime and target once. However, repeated presentation of primes and targets is not unusual in masked priming paradigms (e.g, Bowers et al., 1998; Damian, 2001) and masked word priming does not interact with repetitions (e.g., Johnston & Castles, 2003). Indeed, unlike long-term priming which is greatly reduced for high-frequency words (e.g., Bowers, 2000), there is only a weak (often null) interaction between priming and frequency in the masked paradigm (cf., Forster, 1998). Consistent with these findings, the overall priming in the present studies was similar in magnitude (44 ms averaging across all conditions and studies) to the duration of the prime (60 ms) as is typical when primes and targets are presented once. To further address this concern we compared priming for the similar and dissimilar words in Experiment 2 when items were presented for the first and second time within a given condition (each item was presented twice in each condition). Priming for the similar items was 50 ms in the first and 50 ms in second repetition, and for the dissimilar items, the corresponding priming scores were 49 and 42 ms. So there are no reasons to assume repetitions affected these results.

In sum, no evidence was obtained for the claim that visual knowledge involved in written word identification is coded in an abstract and specific format in the left and right hemispheres, respectively. Whether these findings undermine the claim that lateralized AVF and SVF systems are involved in word identification, or only provide constraints under which these systems function, remains to be seen. But whatever the fate of the two-systems hypothesis, it is important to emphasize that it raises a fundamental question that has largely been ignored; namely, how do perceptual systems identify information at both abstract and specific levels, and the related question as to how abstract and specific knowledge contribute to word identification? Additional research into this issue, both in the domains of word and object identification, is clearly needed.

References

Biederman, I. (1987). Recognition-by-Components—a theory of human image understanding. *Psychological Review, 94*, 115–147.

Biederman, I., & Cooper, E. E. (1991). Object recognition and laterality—Null Effects. *Neuropsychologia, 29*, 685–694.

Bodner, G. E., & Masson, M. E. J. (1997). Masked repetition priming of words and nonwords: Evidence for a nonlexical basis for priming. *Journal of Memory and Language, 37*, 268–293.

Boles, D. B., & Clifford, J. E. (1989). An upper- and lowercase alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments, and Computers, 21*, 579–586.

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

Bowers, J. S. (2000). In defense of abstractionist theories of word identification and repetition priming. *Psychonomic Bulletin & Review, 7*, 83–99.

Bowers, J. S., & Michita, Y. (1998). An investigation into the structure and acquisition of orthographic knowledge: Evidence from cross-script Kanji-Hiragana priming. *Psychonomic Bulletin & Review, 5*, 259–264.

Bowers, J. S., Vigliocco, G., & Haan, R. (1998). Orthographic, phonological, and articulatory contributions to masked letter and word priming. *Journal of Experimental Psychology-Human Perception and Performance, 24*, 1705–1719.

Bryden, M. P., & Allard, F. (1976). Visual hemifield differences depend on typeface. *Brain and Language, 3*, 191–200.

Brysbaert, M. (2004). The importance of interhemispheric transfer for foveal vision: A factor that has been overlooked in theories of visual word recognition and object perception. *Brain and Language, 88*, 259–267.

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.

Coltheart, M. (1981). Disorders of reading and their implications for model of normal reading. *Visible Language, 3*, 245–286.

Damian, M. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 154–165.

Davis, C., & Forster, K. I. (1994). Masked orthographic priming—the effect of prime target legibility. *Quarterly Journal of Experimental Psychology Section A Human Experimental Psychology, 47*, 673–697.

Dehaene, S., Le Clec'H, G., Poline, J. B., Le Bihan, D., & Cohen, L. (2002). The visual word form area: A prelexical representation of visual words in the fusiform gyrus. *Neuroreport: For Rapid Communication of Neuroscience Research, 13*, 321–325.

Ellis, A. W. (2004). Length, formats, neighbors, and the processing of words presented laterally or at fixation. *Brain and Language, 88*, 355–366.

Ellis, A. W., Brooks, J., Lavidor, M. (in press). Evaluating a split fovea model of visual word recognition: Effects of case alternation in the two visual fields and in the left and right halves of words presented at the fovea. *Neuropsychologia*.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *Quarterly Journal of Experimental Psychology Section A Human Experimental Psychology, 33*, 325–350.

Farah, M. J. (1990). *Visual agnosia: Disorders of object recognition and what they tell us about normal vision*. Cambridge, Massachusetts: MIT Press.

Fendrich, R., Wessinger, C. M., & Gazzaniga, M. S. (1996). Nasotemporal overlap at the retinal vertical meridian—investigations with a callosotomy patient. *Neuropsychologia, 34*, 637–646.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Geffen, G., Bradshaw, J. L., & Nettleton, N. C. (1972). Hemispheric asymmetry: Verbal and spatial encoding of visual stimuli. *Journal of Experimental Psychology, 95*, 25–31.

Gibson, A. R., Dimond, S. J., & Gazzaniga, M. S. (1972). Left field superiority for word matching. *Neuropsychologica, 10*, 463–466.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition—effects of masked homophone primes. *Journal of Memory and Language, 33*, 218–233.

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.

Hintzman, D. L. (1986). Schema abstraction in a multiple-trace memory model. *Psychological Review, 93*, 411–428.

Hummel, J. E., & Stankiewicz, B. J. (1998). Two roles for attention in shape perception: A structural description model of visual scrutiny. *Visual Cognition, 5*, 49–79.

Humphreys, G. W., Besner, D., & Quinlan, P. T. (1988). Event perception and the word repetition effect. *Journal of Experimental Psychology: General, 117*, 51–67.

Johnston, M. B., & Castles, A. E. (2003). Dissociating automatic orthographic and phonological codes in lexical access and lexical acquisition. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: State of the art* (pp. 193–222). Hove, UK: Psychology Press.

Koivisto, M. (1995). On functional brain asymmetries in perceptual priming. *Brian and Cognition, 29*, 36–53.

Knapp, A. G., & Anderson, J. A. (1984). Theory of categorization based on distributed memory storage. *Journal of Experimental psychology learning, memory and cognition, 10*, 616–637.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after broadbent (1958): Still no identification without attention. *Psychological Review, 11*, 880–913.

Marsolek, C. J. (1999). Dissociable neural, subsystems underlie abstract and specific object recognition. *Psychological Science, 10*, 111–118.

Marsolek, C. J., & Hudson, T. E. (1999). Task and stimulus demands influence letter-case specific priming in the right cerebral hemisphere. *Laterality, 4*, 127–147.

Marsolek, C. J., Kosslyn, S. M., & Squire, L. R. (1992). Form-specific visual priming in the right cerebral hemisphere. *Journal of Experimental Psychology Learning Memory and Cognition, 18*, 492–508.

Marsolek, C. J., 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.

McClelland, J. L., & Rumelhart, D. E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General, 114*, 159–188.

Neumann, O., Esselmann, U., & Klotz, W. (1993). Differential effects of visual-spatial attention on response latency and temporal-order judgment. *Psychological Research, 56*, 26–34.

Nicholas, C. D., Marsolek, C. J. (1996). *Differential interhemispheric transfer for abstract and specific visual-form information*. Presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97–113.

Pexman, P. M., Lupker, S. J., & Jared, D. (2001). Homophone effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 139–156.

Polk, T. A., & Farah, M. J. (2002). Functional MRI evidence for an abstract, not perceptual, word-form area. *Journal of Experimental Psychology: General, 131*, 65–72.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Rajaram, S., & Roediger, H. L. (1993). Direct comparison of 4 implicit memory tests. *Journal of Experimental Psychology: Learning Memory and Cognition, 19*, 765–776.

Rayner, K., & Sereno, S. C. (1994). Eye movements in reading: Psycholinguistic studies. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 57–81). San Diego, CA: Academic Press.

Ratinckx, E., & Brysbaert, M. (2002). Interhemispheric Stroop-like interference in number comparison: Evidence for strong interhemispheric integration of semantic number information. *Neuropsychology, 16*, 217–229.

Scharlau, I., & Neumann, O. (2003). Temporal parameters and time course of perceptual latency priming. *Acta Psychologica, 113*, 185–203.

Segalowitz, S. J., & Stewart, C. (1979). Left and right lateralizaion for letter matching: Strategy and sex differences. *Neuropsychologia, 17*, 521–525.

Shillcock, R., Ellison, T. M., & Monaghan, P. (2000). Eye-fixation behaviour, lexical storage and visual word recognition in a split processing model. *Psychological Review, 107*, 824–851.

Tarr, M. J. (1995). Rotating objects to recognize them—a case-study on the role of viewpoint dependency in the recognition of 3-dimensional objects. *Psychonomic Bulletin & Review, 2*, 55–82.

Tarr, M. J., & Gauthier, I. (1998). Do viewpoint-dependent mechanisms generalize across members of a class?. *Cognition, 67*, 73–110.

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

Tootell, R. B. H., Switkes, E., Silverman, M. S., & Hamilton, S. L. (1988). Functional anatomy of macaque striate cortex: II. Retinotopic organization. *Journal of Neuroscience, 8*, 1531–1568.

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*, 221–243.