Visual Word Recognition in the Left and Right Hemispheres

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Full Report of Research Activities and Results

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Background:

The perceptual representations that underlie written word identification have been characterized in two fundamentally different ways. On the one hand, it has been argued that these representations--so-called orthographic codes--are coded abstractly such that different exemplars of a given stimulus map onto the same code (e.g., READ/read map together; Morton, 1979). On the other hand, it has been argued that episodic traces of all words are represented within the visual system, and orthographic representations are the product of all these specific codes (Jacoby, 1983). On this view, word recognition involves comparing a given input to all of the specific perceptual instances of words encoded in memory, and these traces interact in such a way that it looks as if abstract codes exist under some conditions.

Evidence for the existence of abstract orthographic codes comes from a variety of sources. For example, Bowers, Vigliocco, and Haan (1998) addressed this question using a short-term priming paradigm in which the identification of target words is facilitated by immediately preceding primes that are undetected due to their brief presentation (e.g., 50 ms). The critical finding was that equivalent priming was obtained between prime-target pairs that are similar (e.g., kiss/KISS) and dissimilar (e.g., read/READ) in lower- and upper-case, suggesting that abstract orthographic codes mediated these effects (also see Coltheart, 1981; Evett & Humphreys, 1981; McClelland, 1976; among others).

By contrast, long-term priming studies are frequently cited in support of the view that specific perpetual codes support word identification. Long-term priming refers to a facilitation in processing a stimulus as a consequence of having encountered the same or related stimulus in an earlier episode. For example, participants are more accurate in identifying a quickly flashed word in a perceptual identification task if it was studied a few minutes or hours previously. Critical for present purposes, there are a number of reports that priming is greater when words are repeated in the same (e.g. table/table) compared to different (e.g., TABLE/table) case (for review of findings, see Tenpenny, 1995, for alternative view, Bowers, 2000). These case-specific priming results are thought to indicate that specific visual features of words are encoded in memory, and the details are relevant for word identification.

Although abstractionist and instance theories of word identification are often considered incompatible, some recent findings suggest a way to reconcile these approaches. That is, there is preliminary evidence that orthographic knowledge is coded in an abstract format in the left hemisphere, and as a collection of perceptual instances in the right hemisphere. Perhaps the most direct support for the two-systems hypothesis was reported in a series of studies employing the long-term priming paradigm. Marsolek and colleagues (e.g., Burgund, & Marsolek, 1997; Marsolek, Kosslyn, & Squire, 1992; Marsolek, Squire, Kosslyn, & Lulenski, 1994) observed that long-term priming for words is insensitive to study-to-test changes in letter-case when the test items are flashed to the right visual field (left hemisphere) and sensitive to these changes when they are flashed in the left visual-field (right hemisphere), suggesting that the word representations are abstract and visually specific in the left and right hemispheres, respectively.

Indeed, this pattern of results may reflect a more basic functional constraint for perceptual systems. The visual system is confronted with two separate recognition problems: It must recognize that different items (a) belong to the same abstract category when they are associated with common post-visual information (e.g., the visual patterns TABLE/table must contact the same semantic codes) yet also (b) belong to different specific categories when items are functionally distinct (e.g., TABLE/table must be distinguished if the task is to categorize upper- and lower-case words). Many contemporary theories ignore these two different requirements, and focus on the accomplishing one these goals. For example, the GEON theory of Biederman (1987) attempts to account for basic object recognition using abstract categories, but this theory cannot explain how different exemplars within a category (e.g. faces) are identified. By contrast, theories of face identification often rely on accessing highly specific perceptual memories, but have difficulty accounting for various abstractions (e.g., mapping together TABLE/table). This has led some to argue that these functions are incompatible, thus requiring different systems (e.g., Farah et al., 1998).

The experiments carried out during the last year further tested the laterality hypothesis by comparing word processing in the left and right visual fields employing various different tasks.

Objectives:

1) The main goal of the present studies was to test the hypothesis that orthographic knowledge is represented in abstract and specific formats in the left and right hemispheres, respectively.

2) The related goal was to determine the range of conditions (if any) in which laterality differences are expressed. That is, laterality differences were tested in a number of different experimental tasks that varied, among other things, the format in which words were displayed (e.g., whether words were degraded or intact) and the dependent measure of interest (e.g., response latencies, accuracy measures, or brain activation). By assessing laterality differences under many conditions, it was hopped that we could provide a stronger test of laterality hypothesis, as well as determine the factors that affect orthographic processing in the two hemispheres.

With regards to objective 1, the results challenge the hypothesis that orthographic knowledge is coded in different formats in the two hemispheres. We demonstrated left hemisphere advantages when processing abstract properties of words, but never obtained evidence that specific visual word processing is lateralized to the right.

With regards to objective 2, we assessed laterality differences with six different experimental tasks, four of which were not included in the original proposal. The additional experiments were included because we failed to obtain the expected laterality differences, and these results could only be taken seriously if they were replicated across a wide variety of experimental conditions. Indeed, in order to maximize the chance to obtain laterality differences, we designed Experiments 3-4 & 5-6 based on claims that laterality differences are most easily observed when participants are required to encode the visual details of words and when specific word identification is not necessary (Burgund & Marsolek 1997). Still, we failed to obtain any evidence for laterality differences – even when we used the same procedures employed by Marsolek (Experiment 6). The failure to obtain clear evidence of laterality differences across a broad range of conditions provides strong constraints on the theory proposed by Marsolek and colleagues. Indeed, given our failure to replicate this pattern of result using his own procedures and materials, the results seriously question this hypothesis.

It should also be noted that we dropped one task (Experiment 5-6 in the original proposal) which involved matching letter strings. These experiments were based on previous findings by Besner et al. (1984), but we subsequently discovered work by Marmurek (1985) showing this task is inappropriate for our purposes.

Methods:

Recruitment Participants were recruited through the Departmental Panel of Participants, and paid either £5 per hour or received course credit. Over 250 students were recruited in total, including those who completed pilot experiments. All the students tested were right handed, half male and half female.

General Methodology and Design. In all studies, participants viewed the materials from a chin-rest so that their eyes were set 50 cm from a computer screen. Each test trial will begin with the presentation of a fixation mark (+), followed by target (or in some cases the prime), with items presented equally often to the left or right of fixation such that the inner edge of items was never less than two-degrees from the fixation mark. Participants could never anticipate the location of the target. In all cases, participants were instructed to look at the fixation point on each trial, and then respond as quickly and accurately on whichever task. Counter-balanced designs were employed in all studies.

Experiments 1a&b: Word Superiority Effect (WSE)

The WSE refers to the higher accuracy rate in identifying briefly flashed words compared to single letters, random letter strings, and pseudowords. Experiments 1a-b compared the identification rates of words and pseudowords presented to the left and right visual fields of participants. Two response techniques were included: (a) a free report task in which participants attempted to report items without cues, and (b) forced choice task in which participants selected one of two alternatives that correspond to the flashed target. The advantage of the former method is that it provides a more sensitive measure of the WSE, and the advantage of the latter is that responses are less subject to guessing biases (McClelland and Johnston, 1977).

In Experiment 1a, all items were presented in lower-case letters to ensure that the WSE was obtained in both hemispheres, and Experiment 1b included items presented in mixed case letters. Words and pseudowords were matched in terms of number of letters, neighborhood density and bigram frequency in an attempt to make the items as similar as possible apart from lexical-status. The critical question was whether the WSE extends to words presented in mixed case letters when items are presented to participants' left visual field (right hemisphere). If abstract codes are restricted to the left hemisphere, the WSE for mixed case words should be reduced in this condition.

Experiment 2: Lexical decisions to proper nouns

Experiment 2 compared response latencies to make lexical decisions to proper nouns that were presented in either a familiar (e.g., Mary) or unfamiliar (mary) format. Past research has demonstrated that lexical decisions can be made more quickly to proper nouns presented in their familiar format when items are presented to the center of fixation (e.g., Gontijo, Shillock and Kelly, submitted; Rueckl & Miner, 1996). Accordingly, in the present experiment, lexical decisions were performed to items presented to the left and right visual fields, in order to determine whether the surface details affected performance more when words were presented to the right hemisphere. An equal number of nonwords were included for the lexical decision task.

Experiment 3: Specific and abstract word categorizations

Experiment 3 included two conditions. In the first, participants were presented with a set of words displayed in different formats (either upper- or lower-case, and italicized or not; e.g., READ, *READ*, read, or *read*), and were required to decide whether pre-specified words were presented in a specific format (e.g., *read*). Because participants needed to encode the detailed visual structure of words, a LVF advantage should be predicted on the two-systems hypothesis. In the second, the same items were presented, but participants decided whether words contained the letter d, irrespective of the format of the word. In this task, the abstract orthographic properties of the words were relevant to task performance, so a RVF advantage was expected.

Experiments 4a-c: Masked Priming

In these experiments, a pattern mask (e.g., ####) was replaced by a briefly flashed word prime displayed in lowercase letters, which in turn will be replaced by an uppercase word target. Primes were presented briefly (60 ms), and participants responded to targets by making lexical decisions, pressing the right shift key to words, and left shift keys to pseudowords (e.g., blap). Priming was measured as the difference in response latencies and error rates to targets preceded by related (e.g. read/READ) compared to unrelated (e.g., data/READ) prime words.

A set of words visually similar (e.g., kiss/KISS) and dissimilar (e.g., read/READ) lower- and upper-case prime-target pairs were presented to the participants' left and right visual fields. The items were high-frequency, which reduces phonological contribution to masked priming (Bowers, Vigliocco, & Haan, 1998). Experiments 4a-c different in terms of the relative positioning of the prime-target pairs as well as the nature of the non-word distracter foils. In Experiment 4a, primes and targets were always presented to the same visual field (left-left or right-right), in Experiment 4b, primes and targets were always presented to the opposite visual field (left-right or right-left), and in Experiment 4c, prime-target pairs were presented in all possible combinations. In Experiments 4a-b, the nonword foils used in the lexical decision task were pronounceable nonwords (e.g. blap), which is typical in most studies (e.g., Forster & Davis, 1984). However, Experiments 4c replaced these nonwords with pseudohomophones that sound like words (e.g., "brane"). Given that these nonwords sound like words, phonology cannot be used to respond, and indeed, the inclusion of pseudohomophones can eliminate phonological priming in the lexical decision task for even low-frequency words (e.g., Ferrand & Grainger, 1996). Accordingly, Experiment 4c provided a stronger control for phonological factors in any cross-case word priming. If abstract orthographic codes are only represented in the left hemisphere, priming for the visually dissimilar prime/target pairs should be reduced when primes are presented to participants' left visual field.

Experiment 5: Stem-completion priming

A stem-completion experiment was carried out in which participants studied a set of visually dissimilar upper- and lower-case words taken from Marsolek (submitted). Each item was presented twice for 1 s in the center of fixation. At test, stems were presented to either the LVF or RVF for 500 ms, and participants named the first word that came to mind. Marsolek and colleagues have reported case-specific and case-insensitive priming in the LVF and RVF under similar conditions (Marsolek, submitted; Marsolek, Kosslyn, & Squire, 1992)

Experiments 6a-b: fMRI imaging study and behavioral analog

In collaboration with Lee Ryan and her colleagues, we are in the process of carrying out an imaging study at the University of Arizona in an attempt to observe laterality differences. In Experiment 6a, written words are presented for 1s one at a time, and participants complete two tasks: a) decide whether the word is typed in italics or normal font (visually specific condition), and b) contain the letter "d", regardless of its visual form (visually abstract condition). In addition, there is a baseline condition in which students passively view a pattern of +++++++. The order of these tasks was counterbalanced. Images from the two experimental conditions were subtracted from the baseline condition, and the prediction from the 2-systems hypothesis is that brain activation should be greater in the right hemisphere in condition a), and greater in the left hemisphere in condition b). In Experiment 6b, the same set of items were presented to participants left and right visual fields, and participants completed the same two tasks. In this case, there should be a left visual field advantage in condition a) and a right visual field advantage for condition b).

Results:

Experiment 1. Word Superiority Experiment

A similar pattern of results was obtained in Experiments 1a-b using the free and forced choice tasks, and accordingly, we only report the analyses to the forced choice task. The identification rate in the various conditions in Experiments 1a-b are presented in Table 1. With regards to the lower-case items, the overall WSE (6.9%) collapsing over frequency was robust, $F(1,20) = 44.5$, $MSe = 25.5$, $p < .01$, and there was an advantage in identifying items presented to the right (92.7%) compared to the left (86.8%) visual field, $F(1,20) = 24.4$, $MSe = 33.9$, $p < .01$. In addition, there was an interaction between item type and hemisphere, $F(1,20) = 7.55$, $Mse = 33.9$, $p < .05$, reflecting a selective difficulty in identifying pseudowords presented to the left visual field. In order to compare the size of the WSE in the various conditions, an ANOVA was carried out the WSE data (identification rate for words minus pseudowords). A main effect of visual field was obtained, reflecting the larger WSE in the LVF (9.7%) compared to RVF (4.0%), $F(1,22) = 6.69$, $Mse = 174$, $p < .05$, as well as an effect of frequency, with a reduced WSE for low-frequency items, $F(2,22) = 3.36$, $Mse = 175$, $p < .05$.

With regards to the mixed-case items, the overall WSE (6.3%) collapsing over frequency was robust, $F(1,20) = 28.0$, $MSe = 34.2$, $p < .01$, and there was an advantage for identifying items presented to the right (85.0%) compared to the left

(80.5%) visual field, F(1,20) = 10.1, MSe = 48.9, p < .01. In order to compare the size of the WSE in the various conditions, an ANOVA was again carried out the WSE data. The only effect was an interaction between visual field and sex of the participant, F(1,22) = 5.41, MSe = 122.6, p < .05, reflecting the relatively small WSE (3.3%) for men when items were flashed to the RVF compared to the LVF, the pattern opposite to what would be expected by the two-systems hypothesis. Finally, an overall ANOVA was carried out on the WSE data combining the lower- and mixed-case words, and case did not interact with any variable, all F values < 1.75, p values > .19. Thus, the WSE was equally robust for mixed case items presented to the left and right visual field, suggesting that orthographic knowledge is equally abstract in the two hemispheres.

Experiment 2: Lexical decisions to proper nouns.

Participants who made more than 20% errors overall were excluded from the analysis. The response latencies and error rates in the various conditions presented in Table 2 (see submitted paper). An ANOVA carried out on the response latencies revealed a main effect of letter case, F(1,12) = 23.5, Mse = 2066, p < .01, reflecting the shorter response latencies to proper names presented in their familiar (610 ms) compared to unfamiliar (665 ms) format, and the effect of visual field approached significance, F(1,12)= 3.04, MSe = 3030, p = .11, reflecting the standard advantage in processing words in the right (626 ms) compared to left (650 ms) visual field. Critically, there was no interaction between letter-case and visual field, F(1,12) < 1, reflecting a similar advantage in the left (63 ms) and right (47 ms) visual fields. The ANOVA carried out on the errors revealed a main effect of letter-case, F(1,13) = 7.67, MSe = 12.2, p < .01, with more errors in the unfamiliar (10.6%) compared to familiar (2.3%) format condition. No other effects approached significance. Laterality differences did not interact with sex of the participants, F(1,14) < 1.

In sum, the present results replicate Rueckl and Miner's (1996) finding that lexical decision response latencies are reduced for proper nouns presented in a familiar format (e.g., Mary rather than mary). But more important for present purposes, we observed the same advantage when items were presented to the left and right visual field. Thus, no evidence was obtained in support of the view that the AVF and SVF systems are lateralized.

Experiments 3: Specific and abstract word categorizations

The response latencies and error rates in the various conditions are presented in Table 3 (see submitted paper). An ANOVA carried out on the RTs revealed a main effect of task F(1,44) = 240, MSe = 37727, p < .01, reflecting the longer latencies to respond in the specific (1029 ms) compared to abstract (594 ms) condition. Task did not interact with visual field, F(1,44) = 1.24, MSe = 2501, p = .27, suggesting that the two tasks were performed equally well in the left and right visual fields. However, planned comparisons indicated that abstract task was performed better in the right (586 ms) compared to left visual (601 ms), F(1,44) = 6.57, MSe = 779, p < .05, whereas for the specific task there was no difference in the right (1029 ms) and left (1029 ms) visual fields, F(1,44) < 1. Overall, response latencies were reduced for women (769 ms) compared to men (853 ms), but sex did not interact with any factor. For errors, there was again a main effect of task, with less errors in the abstract (5.2%) compared to the specific (9.9%) task. No other interactions or contrasts approached significance. Thus, the standard right visual field advantage was obtained for the abstract processing task, but no evidence was obtained for a specific visual processing advantage in the left visual field.

Experiments 4a-c: Masked Priming

The response latencies and error rates of Experiments 4a-c are presented in Tables 4 and 5, respectively (see submitted paper). In Experiment 4a, the overall ANOVA carried out on the RT data revealed a main effect of visual field, $F(1,23) = 17.11$, $MSe = 1899$, $p < .01$, reflecting a reduced latency to respond to words presented to the right (582 ms) compared to the left (608 ms) visual field, and an main effect word type, $F(1,23) = 6.62$, $MSe = 597$, $p < .05$, 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, $F(1,23) = 108.55$, $MSe = 593$, $p < .01$. An overall ANOVA carried out on the priming scores (baseline RTs minus repeated RTs) that included sex as a factor failed to obtain any effects, indicating that a similar amount of priming was obtained across all conditions for both the male and female participants. For errors, the only significant main effect was visual field, with fewer errors in the right (3.2%) compared to left (5.0%) visual field, $F(1,23) = 4.88$, $MSe = 32.6$, $p < .05$.

In Experiment 4b, the ANOVA carried out on the response latencies revealed a significant 42 ms priming effect, $F(1,23) = 88.74$, $Mse= 985$, $p < .01$, and no other effects approached significance. An ANOVA carried out on the priming scores also failed to reveal any significant effects, indicating that a similar amount of priming was obtained across all conditions for both the male and female participants. For errors, the only significant effect was for visual field, with fewer errors in the right (5.6%) compared to left (8.4%%) visual field, $F(1,23) = 4.39$, $MSe = 89.82$, $p < .05$.

In Experiment 4c, the overall ANOVA carried out on the RT data revealed a main effect of visual field, $F(3,35) = 32.06$, $MSe = 2360$, $p < .01$, reflecting the faster responses when primes and targets were presented to the same visual field, and a main effect of word type, $F(1,15) = 7.27$, $MSe = 2080$, $p < .05$, reflecting the faster response to the visually similar (567 ms) compared to dissimilar (582 ms) target words. Furthermore, a priming effect of 43 ms was significant, $F(1,15) = 54.46$, $MSe = 2180$, $p < .01$. 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 LVF and targets to the RVF. However, the same pattern was obtained for the visually similar and dissimilar prime-target pairs, $F(3,42) < 1$, indicating that this contrast does not reflect any differences in the processing of abstract and specific visual knowledge in the two hemispheres. In terms of errors, there was a main effect of visual field, $F(3,45) = 10.11$, $MSe = 62.21$, $p < .01$, with reduced errors in the RVF-RVF condition. The analysis on the priming scores only showed a main effect of sex, with more priming for woman (2.5%) compared to men (-.4% ms). No other main effect or interaction approached significance.

In sum, a similar pattern of priming was obtained for visually similar and dissimilar prime-target pairs when items were presented to the left or right visual field. Accordingly, the masked priming results provide no evidence in support of the two-systems hypothesis

Experiment 5: Stem-completion priming

The percentage of stems completed as study items in the various conditions are presented in Table 6 below. A main effect of visual field was obtained, reflecting a higher proportion of items presented to the LVF, F(1,30) = 9.05, Mse = 124, $p < .01$, as well as a main effect of priming, F(2, 60) 53.37, Mse = 164.5, $p < .01$. In order to determine whether the amount of priming varied across conditions, an ANOVA was carried out on the difference scores (percentage of stems completed as study item in the repeated condition minus the percentage of items completed in the baseline condition), and there was no effect of visual field nor an interaction with sex, all F values < 1. Thus, there was no evidence that orthographic knowledge is coded in a more specific format in the right hemisphere.

Table 6: Percentage of stems completed as study words.

	Same case	Different case	Baseline
Visual field			
Left	42.9	35.4	20.2
Right	37.5	30.4	16.9

Experiment 6a-b: fMRI imaging study and behavioral analog

At present, six participants have been tested in Experiment 6a, and the results of a single participant are presented in the Appendix that includes Figures 1 and 2. In these images, brain activity in the abstract and specific word tasks was subtracted from a fixation condition (++++++), although the same results were obtained with other baseline conditions. The orange squares reflect activation following the subtraction, and the right side of the brain image corresponds to the left hemisphere. The different images reflect different horizontal brain sections. As can be seen, there is slightly more activation in the left hemisphere than right in both tasks. The same pattern is obtained in all six participants, thus providing no support for the lateralization hypothesis.

In Experiment 6b, the overall ANOVA revealed an effect of task, with shorter response latencies to the italics (599 ms) compared to the d (639 ms) task, F(1,44) = 21.12 Mse = 3711, $p < .01$, and the interaction between task and hemisphere approached significance, F(1,44) = 3.26, Mse = 552, $p = .08$, reflecting the RVF advantage (10 ms) for the d task, and the absence of any a LVF advantage (2 ms) for the italics task. No effect was obtained on the errors. So again, no evidence for the laterality hypothesis was obtained.

Activities:

Some of these results have been discussed at an invited talk at the CNR, Paris. Bowers (2000). Long-term priming for visual words is an incidental by-product of learning within the orthographic system.

Outputs:

Bowers, J.S. & Turner, E. (2000). In search of abstract and specific visual form systems in the left and right hemispheres. Submitted to Journal of Experimental Psychology: Learning, Memory, and Cognition.

Bowers, J.S., Ryan, L., Jain, S. & Turner, E. (in progress). Assessing abstract and specific visual word processing in a behavioral and imaging study.

Future research directions:

Given the failure to obtain any evidence for AVF and SVF systems lateralized in the left and right hemispheres, respectively, there are reasons to test alternative hypotheses. One recent hypothesis is that both functions are supported by a single system, and that attention plays a key role in determining the level at which inputs are categorized (Hummel & Stankiewicz, 1998). In future work, we intend to pursue this idea by determining whether abstract and specific long-term priming effects can be modulated by attention. We will not be seeking ESRC funding for this project, however.

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