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Letter identification processes in reading: Distractor interference reveals an automatically engaged, domain-specific mechanism

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Recent neuroimaging studies have revealed that letters activate both the left and the right fusiform areas, but that only the left fusiform responds to letters more than to control stimuli (Cohen et al., 2003). Though these findings suggest that the left fusiform is specialized in its function of identifying letters, it does not rule out the possibility that the right fusiform contributes critically to letter identification processes. We used a behavioural word identification task in which we compared bilateral and unilateral displays to determine the cost of engaging the right hemisphere with a distractor stimulus. We found that while engaging the left hemisphere led to a robust interference effect, engaging the right hemisphere had no effect at all. We were able to rule out an attentional bias to the right visual field as a possible explanation of the asymmetrical interference effect. We conclude that while the right hemisphere may be able to assume letter identification processing responsibilities in some patients with brain damage, the right hemisphere does not contribute critically to abstract letter identification processes in healthy right-handed individuals.

Written language is a uniquely human development and constitutes one of humankind's greatest cultural achievements. Unlike other aspects of language processing, though, for which even very young infants exhibit surprising capabilities (e.g., speech perception, Werker & Tees, 1984), reading processes are acquired relatively late in life and must be learned through explicit instruction. Also, written language did not develop until just recently in our evolutionary history. Taken together, these two facts suggest that it is very unlikely that reading processes reflect the natural unfolding of a genetic programme. Thus, it is reasonable to consider the possibility that, at the functional level, reading processes are subserved by domain-general cognitive mechanisms. On the other hand, it seems equally reasonable to think that the language system may co-opt reading processes and, hence, that reading processes may be subserved by a domain-specific (language) mechanism.

A corollary issue, and one that has been vigorously debated in the literature, has to do with isolating the neural mechanisms that support reading processes. Are these neural mechanisms strongly lateralized to one hemisphere, or are they distributed across the two hemispheres? The literature on the laterality of reading processes is mixed

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at best, with a wide variety of different findings having been reported and theoretical accounts proposed. This lack of consensus in the literature may, in part, be due to the fact that "reading processes" subsume several stages of processing, with each stage recruiting different neural mechanisms (Coltheart, 1980; Dehaene et al., 2004). In this article, we focus on the earliest stages of the reading process and, specifically, on letter identification processes.

At minimum, reading requires determining *what* letters are present in the string of letters comprising the word stimulus, and *where* in the letter string those letters are located—although recent work investigating reading processes with transposed letters suggests a certain degree of tolerance with respect to letter location (Perea & Lupker, 2003). Subsequently, the "what" and "where" information extracted from the stimulus is represented in an abstract form, which, in turn, is used to access the orthographic input lexicon. Accessing the orthographic (lexical) representation that corresponds to the input stimulus serves to make available the stored information about that word (e.g., its meaning and its pronunciation). It is generally agreed upon that two preliminary steps are required to arrive at the abstract representation used to access the orthographic input lexicon. In the first of these two steps, the shapes, sizes and orientations of the letters must be determined. We refer to this first step as *letter shape detection*. The second preliminary step, which we refer to as *abstract letter identification*, involves determining the abstract letter identity (ALI) or grapheme for each individual letter shape in the letter string.[1] Abstract letter identities are needed to mediate between the input stimulus and the orthographic lexical representation. There is a tremendous amount of variation present in the input (e.g., 𝓡, *r*, ℛ, 𝓇), especially in handwritten text, and this variability increases the difficulty of the mapping problem between the physical features of letter shapes and their corresponding invariant representations in the orthographic input lexicon. Abstract letter representations, on the other hand, have the advantage of enjoying well-established connections to the orthographic input lexicon. The two preliminary steps of reading processes are depicted in Figure 1. We should be clear that the steps of letter shape detection and abstract letter identification are depicted simply as logical requirements, not discrete stages of processing. It may be, for example, that the processing from input stimulus to ALI selection is graded and continuous (Cohen et al., 2003).

The majority of empirical evidence supporting the involvement of these two preliminary steps has come from investigations of neurologically impaired patients (e.g., Caramazza & Hillis, 1990; Haywood & Coltheart, 2001). In one of the most striking cases that have been reported, Miozzo and Caramazza (1998) describe a patient (G.V.) with "pure alexia" who was completely unable to read aloud words (0/70 correct). G.V.'s inability to read these words did not originate from a damaged orthographic input lexicon, though, as she was able to recognize all 70 of those same words when they were orally spelled for her. Nor did her reading deficit arise from an inability to process low-level perceptual information as she was flawless in discriminating between real and pseudoletters (e.g., p vs. þ) and was within the normal range in discriminating between normally oriented and reflected characters. Likewise, when G.V. was asked to indicate whether same-case letters had the same name or not (e.g., A–A, A–B), she was correct 93% of the time. Rather, G.V.'s reading deficit seems to be located at the second of the two preliminary stages of reading: determining the abstract letter identity for each letter shape. For example, when asked to indicate whether different-case letters had the same name or not (e.g., A–a, A–b), performance dropped down to just above chance. Similarly, when asked to transcribe a visually presented letter in its other case (e.g., A → a, q → Q), she was correct only 37% of the time. Taken

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[1] In this article, we use the terms "abstract letter identity" (ALI) and "grapheme" interchangeably.

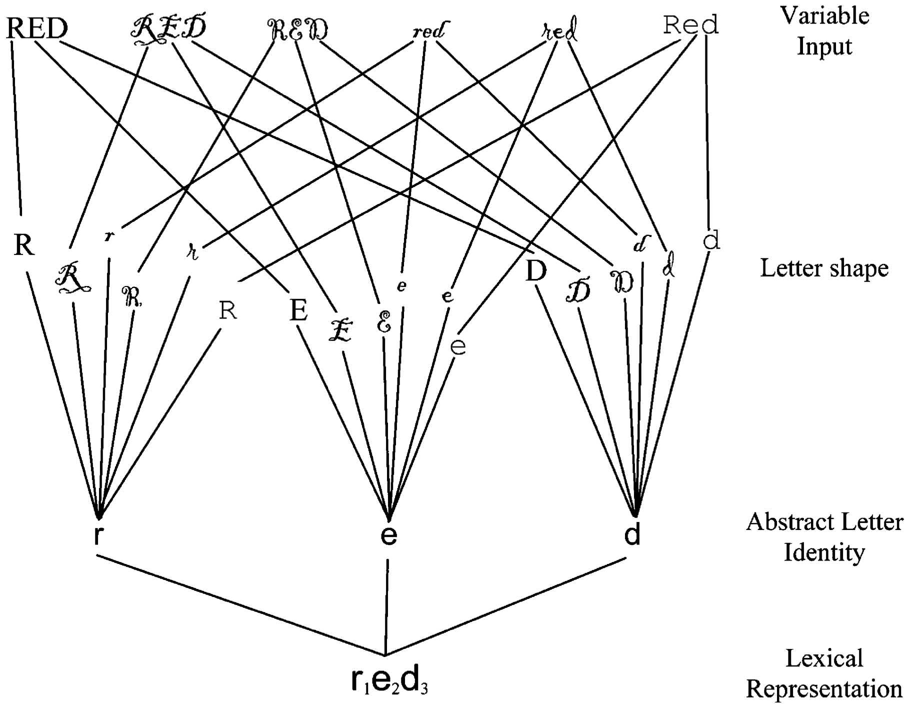

Figure 1. *A depiction of the two preliminary stages in reading. Because a letter can come in many different shapes, an abstract letter identity (ALI) is needed to mediate between the variable input and the lexical (orthographic) representation. First, letter shapes are detected, then ALIs are selected. Once the ALIs have been determined, the orthographic input lexicon can be accessed.*

together, G.V.'s performance suggests that her reading deficit stemmed from a failure to access abstract letter identities from otherwise intact and correctly computed letter shapes.

Similarly, Chanoine, Teixeira Ferreira, Demonet, Nespoulous, and Poncet (1998) report a patient (C.N.) with pure alexia who, much like G.V., could discriminate between real and pseudo letters, but was greatly impaired at selecting which two letters out of four (e.g., G, C, g, t) had the same name. Chanoine et al. concluded that this patient could access coarse visual information about letters (such as letter shapes and orientations) but could not access more abstract alphabetical representations from visual input.

An interesting question that arises from this analysis of the reading process has to do with the possible lateralization of any or all stages of the letter identification process. In the case of patient G.V., her lesion was in the left occipital and posterior temporal areas and extended to the corpus callosum. A magnetic resonance imaging (MRI) scan also revealed an additional area of hypodensity in the right parietal region, although a battery of neuropsychological tests revealed no evidence of a right parietal deficit (e.g., no signs of visual neglect). Similarly, patient C.N.'s lesion (Chanoine et al., 1998) was also isolated to the left hemisphere (left occipito-temporal lesion that extended to the corpus callosum). Miozzo and Caramazza (1998) concluded from these two patients that "only representations about the shape and orientation of letters are encoded in the right hemisphere [and that] graphemic representations of letters are stored in the left hemisphere".

Neuroimaging work with neurologically intact individuals has provided some support for the possibility of a left-lateralized letter identification mechanism (Cohen et al., 2003; McCandliss, Cohen, & Dehaene, 2003). For example, Cohen et al. (2003) found that the so-called visual word form area (VWFA)[2] in the left fusiform was activated by alphabetic stimuli, including consonant strings, relative to a checkerboard; the right hemisphere homologue reacted identically to both alphabetic and checkerboard stimuli. This finding suggests that while the right hemisphere homologue of the VWFA is engaged by letter stimuli, it does not appear to process letters as anything more than meaningless shapes. Similarly, Dehaene et al. (2001), using a masked priming technique, found that the left fusiform exhibited both case-specific and case-independent priming whereas the right fusiform only exhibited case-specific priming—priming between prime–target pairs of the same case. More recently, Dehaene et al. (2004) confirmed that the masked repetition priming effect in the left fusiform was independent of visual similarity by comparing priming for words like *rage–RAGE*, which have dissimilar lower- and upper-case letters, and *coup–COUP*, which have similar lower- and upper-case letters. Dehaene et al. (2004) report a priming effect (decreased activation) in the left fusiform for both similar and dissimilar prime–target pairs; in the right fusiform, a marginal effect ($p = .066$) was observed for similar pairs but no effect at all for dissimilar pairs. Along these same lines, Polk and Farah (2002) have shown that equally robust functional MRI (fMRI) responses (relative to a control stimulus) are obtained in the left-lateralized visual word form area for words presented in a familiar format (e.g., "table") and in a perceptually novel format (e.g., "tAbLe"). These findings have been taken in support of the possibility that the processes carried out in the VWFA are relatively abstract and that they have become attuned to the specific demands of computing abstract letter identities that are invariant with respect to spatial position, size, font, or case (Cohen et al., 2003; McCandliss et al., 2003).

Despite the neuroimaging results with normal individuals, which are quite compelling in suggesting that the left fusiform is involved in the processing of abstract letter identities and that the right fusiform is involved in the processing of letters as physical shapes only, there is evidence from neuropsychological patients that the right hemisphere may be able to develop the means to process letters qua letters. For example, Coltheart (1980, 2000) has suggested that deep dyslexic patients, who produce semantic errors when reading aloud, rely upon the right hemisphere to process the orthographic stimulus and then pass this information along to the left hemisphere for the retrieval of phonological information and subsequent articulation. In one line of support for Coltheart's right-hemisphere reading proposal, Saffran, Bogyo, Schwartz, and Marin (1980) found that patient V.S., a deep dyslexic, exhibited a left-visual-field (LVF) advantage in a lexical decision task. This is quite surprising given how robust the right-visual-field (RVF) advantage is for normal individuals (Leiber, 1976; Young & Ellis, 1985). These authors followed up their initial study with a series of experiments and found that using a bilateral display enhanced the LVF advantage in two of three deep dyslexics. Saffran et al. (1980) took this finding to imply that the LVF stimuli engaged reading processes in the right hemisphere (RH), which, in turn, impeded the transfer of information from the left hemisphere (LH; which was unable to read the RVF stimuli) to the RH.

In another line of support for the RH reading proposal, Coslett and Saffran (1989, 1992, 1994) reported patients C.B. and E.M. who, like patient G.V. described above (Miozzo & Caramazza, 1998), were dramatically impaired in their ability to read the stimuli explicitly, but, surprisingly, were able to perform lexical decision and semantic categorization tasks remarkably well. Coslett and Saffran (1994) and Saffran and

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[2] It should be noted that the name of this region, "visual *word* form area", is somewhat misleading. The so called VWFA responds to a wide range of visual stimuli, not just words (Price & Devlin, 2003). With respect to alphabetic stimuli, consonant strings produce more activation in the VWFA than checkerboards, and real words produce more activation than consonant strings (Cohen et al., 2002). However, words do not produce more activation than pseudowords (Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002).

Coslett (1998) have taken these findings to mean that the both the LH and RH are equally capable of processing letter shapes and abstract letter identities and accessing the orthographic input lexicon, but that only the LH is able to process the phonological features of words. According to this proposal, pure alexic patients are unable to read aloud visually presented words because the type of lesion that typically produces pure alexia (LH occipital areas and the corpus callosum) effectively isolates the language production system in the left hemisphere from the visual input. Left intact, though, are the RH reading mechanisms. Hence, following from Coslett and Saffran's model of reading (1994; Saffran & Coslett, 1998), performance on implicit reading tasks such as lexical decision or semantic categorization is directly attributable to RH mechanisms. Perhaps the strongest support for the RH reading proposal comes from a transcranial magnetic stimulation (TMS) experiment with a patient (J.G.) who had partially recovered from pure alexia. In this experiment, Coslett and Monsul (1994) found that TMS over the right, but not left, posterior temporal lobe and angular gyrus disrupted this patient's ability to read. These findings indicate that the RH was critical to whatever reading processes this patient was able to engage (but see Chialant & Caramazza, 1998).

One possibility is that the RH homologue of the VWFA is able to take up abstract letter identification following brain injury to the left hemisphere VWFA.[3] This possibility seems all the more reasonable given the fMRI findings that the RH homologue already responds, albeit not selectively, to letter strings in normal individuals (Cohen et al., 2003). Consistent with this possibility are findings from a recent neuroimaging study by Cohen et al. (2004). These authors used fMRI to compare normal reading processes with those of a patient (C.Z.) whose left occipitotemporal regions were surgically removed in the resection of a tumour. Six months after her surgery, C.Z.'s right fusiform responded selectively to letter strings versus checkerboards. This pattern contrasted sharply with the normals in the study who were tested with the same materials and tasks and for whom only the left fusiform responded selectively to letter strings (see also Cohen et al., 2003, described above).

The purpose of this short review is to reveal that on one hand there is compelling evidence both from patients with pure alexia and from neuroimaging studies of normal individuals that abstract letter identification processes are carried out by the left hemisphere and that right hemisphere processing is restricted to letter shape detection. This is corroborated by a long history of behavioural findings that reveal a RVF–LH advantage in reading tasks (e.g., Leiber, 1976). On the other hand, though, this review has made clear that there is evidence that suggests that reading may be subserved by RH mechanisms in some patients with LH damage. The question raised by the findings reviewed here is, what function does the RH homologue have in normal individuals, if it has any at all? Is this region simply "going through the motions" of reading without making any contribution to the process? Or does the RH homologue of the VWFA actively participate in and contribute to normal reading processes? Neuroimaging studies have not yet been able to answer this question definitively because, although it is possible to use fMRI to reveal that only the VWFA is selectively engaged by letter strings, this does not rule out the possibility that the nonselective activation in the RH homologue nevertheless contributes critically to the reading process. One way to begin teasing these two possibilities apart would be to use a behavioural task to determine the cost of engaging the RH homologue when performing a simple reading task. In the present article, we do just this.

The experimental paradigm that we use compares performance between unilateral and bilateral displays (Boles, 1990, 1994). The reasoning for employing this particular approach is as follows.

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[3] On this account, it is unclear why patient G.V. (Miozzo & Caramazza, 1998) or C.N. (Chanoine et al., 1998) did not exhibit any RH reading. It may be that the degree to which letter identification processes are lateralized premorbidly affects the likelihood of RH reading mechanisms from becoming engaged following LH damage (cf. Knecht et al., 2002).

Assuming that the VWFA and its RH homologue are critical to normal word recognition processes and that the process of identifying letters is subserved by a capacity-limited mechanism (cf. Saffran et al., 1980), then engaging the VWFA or its RH homologue should produce a noticeable cost. That is, we can predict that performance in the bilateral condition will be impaired relative to the unilateral condition because in the bilateral condition a distractor stimulus engages the contralateral letter identification area, thereby decreasing that area's ability to contribute to the recognition of the target stimulus. Essentially, the cost attributed to the display type manipulation (bilateral display vs. unilateral display) should be directly proportional to the degree in which the engaged mechanism (in the bilateral condition) is critical to the letter identification process. Hence, if the cost attributed to the distractor stimulus in the bilateral display condition is robust in one hemisphere but nonexistent in the other, we may conclude that the hemisphere that fails to exhibit a cost is not critical to normal letter identification processes.

In the following series of experiments, we compare participants' performance in a word identification task between unilateral and bilateral display conditions. To anticipate our findings briefly, we report significant display type by visual field interactions in which participants' ability to identify targets in the LVF (RH) was found to be significantly and uniquely impaired in the bilateral display condition compared to the unilateral display condition. Display type did not affect participants' ability to identify targets in the RVF. The findings from a series of follow-up experiments allow us to rule out the possibility of a RVF attentional bias as a possible account for the data and to conclude that while the LH mechanism is critical to the letter identification process in healthy brains, the RH mechanism is not.

EXPERIMENT 1

In this experiment we investigated whether or not the RH is critically involved in word recognition by seeing whether a distractor word presented in the LVF (projected to the RH) would adversely affect participants' ability to identify a simultaneously presented target word in the RVF (LH). Pursuing this line of experimentation first required resolving two methodological questions. The first of these involved determining how the participants should be informed as to what visual field contained the target. Previously, this has been done by presenting an arrow head (e.g., >) at fixation to tell the participant which stimulus should be considered for a response (Boles, 1994). We chose not to use this procedure out of concern that participants may be able to use such a cue effectively to avoid attending to the distractor stimulus, and, after all, we were interested in the potential effects of attending to the distractor stimulus. Instead, we chose to use a "visual search" procedure, where participants had to indicate whether or not a word that referred to an animal was present in the display. Hence, participants were instructed to respond positively when they detected the presence of an animal word and negatively when they failed to detect the presence of an animal word. In this way, we could be relatively certain that participants were attending to stimuli in both the right and the left visual fields.

The second methodological issue involved choosing an appropriate dependent variable. In previous studies, the primary variable of interest has been reaction times. Given the motivation for the present study, though, we reasoned that the percentage of targets missed would be a more informative measure. We are interested in measuring the *cost* of engaging the contralateral hemisphere with a distractor stimulus, and the most powerful demonstration of this cost would be to show that distractor stimuli can prevent the detection of target stimuli.

Method

Participants

A total of 14 undergraduate students at Harvard University participated for course credit or payment. All participants were native speakers of

English, had normal or corrected-to-normal vision, and were strongly right-handed. Handedness was assessed using the Edinburgh Handedness Inventory, which yields a laterality quotient that ranges from 1.0 (extreme right handedness) to −1.0 (extreme left handedness). The mean laterality quotient (LQ) for the participants in Experiment 1 was .78.

Materials

A total of 20 animal words were selected (e.g., seal, goat) and were used as targets. Additionally, 20 words were selected to be used as foils on the No trials. Pilot testing revealed that participants were able to generate a response in this task on the basis of partial orthographic information (i.e., a word ending in "-nt" is "elephant"). As such, foils were selected on the basis of their orthographic similarity to the animal word targets. For example, the word "boat" was selected as a foil for the animal target "goat", and "sleep" was selected as a foil for "sheep". This ensured that participants would have to analyse the letter identities of each stimulus to perform the task. None of the foils were animal words. In addition, 20 distractor words were selected to be used on the bilateral display trials. The distractor words matched the target words on average frequency and length. Again, none of the distractor words were animal words. A complete list of materials is available in Appendix A.

Procedure

Participants responded by pressing one of two buttons. The buttons were aligned perpendicularly to the computer monitor, and participants responded positively by pressing the farthest button with their dominant hand (right). Likewise, participants were instructed to press the button closest to themselves with their non-dominant hand (left) when the display did not contain an animal word. The instructions emphasized the importance of accuracy, and participants were told not to worry about how quickly they responded. Participants were told that the purpose of the experiment was to test peoples' ability to identify words in the periphery. As such, participants were strongly encouraged to fixate centrally and to monitor for the presence of animal words with their peripheral vision. The DMDX software package (Forster & Forster, 2003) was used to control the display of items and to record participants' responses.

Participants were seated approximately 50 cm from a flat-screen computer monitor in a dimly lit and sound-attenuating testing booth. Each trial began with the presentation of two forward masks (########), one on each side of a centrally located fixation point (+) for 500 ms. The masks subtended 5.0° × 0.7° visual angle with an inner-most edge at approximately 3.5° from the central fixation point. All stimuli, including the masks, were centred on points approximately 6° from the central fixation point. In the case of a bilateral display trial, the forward masks were replaced with either a target or a foil word on one side of fixation and a distractor word on the other side of fixation. In the case of a unilateral display trial, a distractor word was not presented, and in its place the forward mask was re-presented (see Table 1 for the four display conditions). After a brief period (see below for how the presentation duration was determined), the bilateral or unilateral display was replaced immediately with the two masks, and the fixation point became a question mark (?), indicating to the participant that they should respond (see Figure 2 for a depiction of the sequence of events in each trial). Upon responding, the next trial began immediately.

Across the experiment, each target and foil stimulus appeared an equal number of times in

Table 1. *The four different display conditions*

Display condition	*Target (yes) trials*			*Foil (no) trials*		
Unilateral left	goat	+	####	boat	+	####
Unilateral right	####	+	goat	####	+	boat
Bilateral left	goat	+	flash	boat	+	flash
Bilateral right	flash	+	goat	flash	+	boat

Note: On each trial a central fixation point was flanked on either the left or the right by a target or foil word. In the unilateral condition, only the target or foil word was presented; in the bilateral condition, a distractor stimulus was presented contralaterally to the target or foil stimulus.

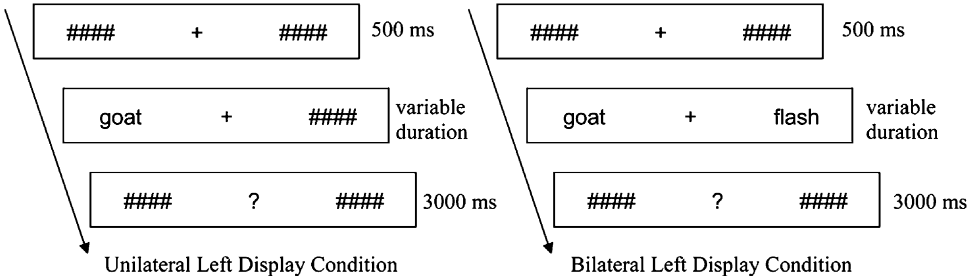

Figure 2. *Sequence of events in each trial in Experiments 1–5.*

each of the four display conditions (unilateral left and right, bilateral left and right). In an effort to keep target and foil displays as comparable as possible, each distractor stimulus was yoked to a single target/foil pair. For example, in bilateral displays, the distractor "flash" appeared with the target "goat" and with the foil "boat". Items were presented in a different fully randomized order within blocks for each participant.

Due to the concern of ceiling or floor-level (and thus uninterpretable) performance, we used an initial staircase procedure to titrate each individual's performance in the most difficult condition (bilateral left) to just-above-chance levels. This procedure ensured that performance in all display conditions was better than chance, but not perfect. The staircase procedure consisted of four blocks of 40 bilateral display trials (20 target and 20 foil trials). The error rate on the bilateral left target trials ($N = 10$) was calculated for each individual after each block and was used to determine the presentation duration in the following block of trials. The titration procedure worked as follows. In the first block, the display duration was set at 300 ms (18 refresh cycles at 60 Hz). If a participant's performance in the bilateral left condition was above chance (50% accurate), the display duration of targets and foils in all four display conditions was decreased. The degree to which the display duration decreased was scaled and depended upon percentage correct. If the percentage of targets missed was 30% or less, the duration decreased 50 ms (three refresh cycles). If the miss rate was between 30% and 40%, the duration decreased 33 ms. If performance in the bilateral left condition fell to chance, the display duration of targets and foils in all four display conditions was increased by one refresh cycle (16.7 ms).

After the staircase procedure, the experiment proper began. The experiment proper consisted of three blocks of 160 trials: 20 target and 20 foil trials in each of the four display conditions. After each block, participants were given the opportunity to take a short break before continuing on to the next block. Again, the error rate for target trials in the bilateral left condition was calculated, and the presentation duration in the following block of trials was increased or decreased accordingly. In total, the experiment took about 35 minutes to complete.

Results

In Experiment 1, the mean display duration across the three test blocks was 150.3 ms. Consistent with what is generally reported in the literature, participants were much better at detecting a target word when it was presented in the RVF than when it was presented in the LVF. The mean error rate for targets (target misses) in the RVF was 18.8% versus an error rate of 35.4% for targets presented in the LVF. This difference was significant in two analyses of variance, one treating subjects as a random effect, $F_1(1, 13) = 7.41$, $p = .01$, and one treating items as a random effect, $F_2(1, 19) = 14.27$, $p < .01$. Similarly, the mean number of target misses in the bilateral display condition ($M = 31.3$) was greater than that in the unilateral display condition ($M = 22.9$), and this difference was significant in both the subjects and the items analyses: $F_1(1, 13) = 6.43, p = .02$; $F_2(1, 19) = 30.02, p < .01$. As can be seen in Figure 3, the display type difference is due almost exclusively to the bilateral left condition, which is confirmed by the statistically significant interaction between the display type and visual field factors: $F_1(1, 13) = 5.91, p = .03$; $F_2(1, 19) = 6.69, p = .03$. The nature of this interaction suggests that the presence of a distractor made it significantly more difficult to detect the presence of a target word, but only when the distractor was presented in the RVF (projected to the LH); a LVF distractor projected to the RH had no effect on participants' ability to detect a target word. Planned comparisons confirmed this by showing that the difference between bilateral and unilateral displays was highly significant when distractors were projected to the LH, $F(1, 13) = 12.80, p < .01$, but not the RH, $F(1, 13) < 1$.

One possible explanation for the observed pattern of performance is that participants adopted different response criteria in the different conditions. To investigate this possibility, the decision criterion statistic, *Z*c (Macmillan & Creelman, 1991; Sorkin, 1999), was calculated for each participant in each display condition. The mean decision criterion was 0.55 and 0.50 for the bilateral left and right display conditions, respectively, and 0.59 and 0.66 in the unilateral left and right display conditions, respectively. A one-way analysis of variance (ANOVA) revealed no effect of display condition ($F < 1$). This suggests that participants did not vary their decision criteria as a function of display condition.

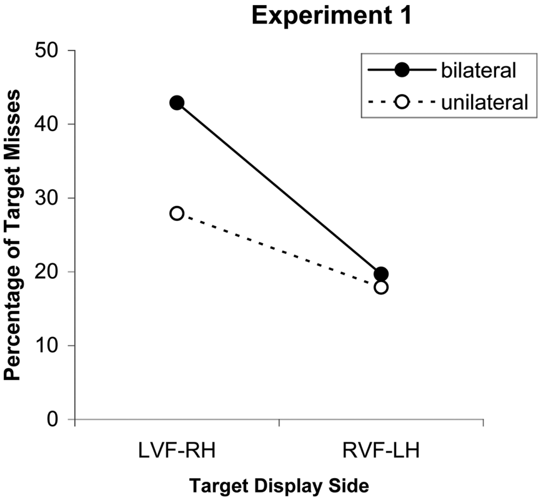

Figure 3. *Error rates (target misses) as a function of presentation condition in Experiment 1 with word distractors.*

Discussion

The question of interest that this experiment was designed to address was whether or not engaging the RH with a distractor word would affect participants' ability to recognize target words. According to the possibility that the RH contributes critically to normal letter identification processes, engaging the RH with a LVF distractor should impair performance (relative to the unilateral condition). This was not observed. Using a LVF distractor word to engage the RH had no appreciable effect on participants' ability to detect the presence of an animal word (in the RVF). In contrast, engaging the LH had a large and adverse effect on participants' ability to detect a target word.

One possible concern in interpreting the interaction obtained in Experiment 1 has to do with the possibility that performance is at ceiling for RVF targets in the unilateral condition—that is, an otherwise present effect of display type for RVF targets goes undetected because performance could not improve beyond 80% correct in the unilateral right condition. Notice, though, that a similar argument could be made for LVF targets in the unilateral condition. It is possible that performance in the unilateral left condition could not improve either (due to the difficulty of detecting LVF targets in this task) but, importantly, the bilateral left condition indicates that the presence of a distractor (in the RVF) was capable of impairing participants' ability to detect LVF targets. The same did not happen when distractors appeared in the LVF. While it may be that the hit rate for detecting RVF targets in the unilateral condition is at ceiling, the important finding here is that projecting a distractor to the RH did nothing to impair participants' detection of RVF targets, and based upon the hit rate in the bilateral left condition, there is sufficient room for performance to be impaired. Yet it is not. Thus it is unlikely that the display type by visual field interaction is due to a ceiling effect in the condition in which targets are presented in the RVF. We take up this concern again in our discussion of the findings in Experiment 3, which help to rule out this possible alternative account.

Although these findings are rather compelling in suggesting that the RH mechanism is not critical to word recognition processes, the locus of the "bottleneck" giving rise to the interference effect is not clear. For example, according to the three stages of word recognition depicted in Figure 1, it could be that the bottleneck is at the point of detecting letter shapes, selecting ALIs, or accessing the orthographic input lexicon. There may be no conclusive way to identify precisely the locus of the effect within these three processing stages, but the use of "neighbourless" consonant strings as distractors may provide some initial insight. Consonant strings (e.g., *xmxm*) that have no orthographic neighbours (Coltheart, Davelaar, Jonasson, & Besner, 1977) are unlikely to activate lexical representations to any significant degree in the input lexicon and, hence, should not compete with a target word for lexical access resources. In contrast, at the prelexical stages of accessing letter shapes and ALIs, any letter string, regardless of whether it has orthographic neighbours or not, could theoretically create just as much interference as a real word. Hence, if letter string like *xmxm* induces just as much interference as do real words (Experiment 1), then we may conclude, albeit somewhat tentatively, that the locus of the interference effect is prelexical. Experiment 2 was designed to test this possibility.

EXPERIMENT 2

Experiment 2 was identical in every way to Experiment 1 except that the distractor words were replaced with illegal consonant strings that had no orthographic neighbours (e.g., xmxm, zxbz).

Method

Participants

Again, 14 undergraduates at Harvard University participated for either course credit or payment. Again, all participants were native speakers of English, had normal or corrected-to-normal vision, and were all strongly right handed (LQ: $M = .80$).

Materials

The materials were identical except that the distractor words were replaced with orthographically illegal, "neighbourless" consonant strings. The program N-Watch (Davis, 2005) was used to calculate the neighbourhood size of each letter string. See Appendix A for a full list of materials.

Results

The mean display duration for all participants across the three test blocks was 185.4 ms. Again, main effects of visual field and display type were obtained. The mean rate of targets missed in the RVF (18.1%) was significantly less than the mean rate of missed targets in the LVF (38.6%): $F_1(1, 13) = 14.4$, $p < .01$; $F_2(1, 19) = 56.8$, $p < .01$. Likewise, there was a significant effect of display type, with more targets (32.2%) missed in the bilateral display condition than were missed in the unilateral display condition (24.5%): $F_1(1, 13) = 9.8$, $p = .01$; $F_2(1, 19) = 14.2$, $p < .01$. Also, just as in Experiment 1, and as is clear from Figure 4, the effect of display type is carried predominantly by the error rate in the bilateral left condition. This is confirmed by a significant interaction between the factors of display type and visual field: $F_1(1, 13) = 6.06$, $p = .03$; $F_2(1, 19) = 10.9$, $p < .01$. Once again, planned comparisons revealed a significant difference between display type for targets that appeared on the left, $F(1, 13) = 10.5$, $p < .01$, but not for targets that appeared on the right, $F(1, 13) = 2.3$, $p > 1$.

Again, the decision criterion (Zc) statistic was calculated for each participant in each display condition. The mean decision criterion statistic was

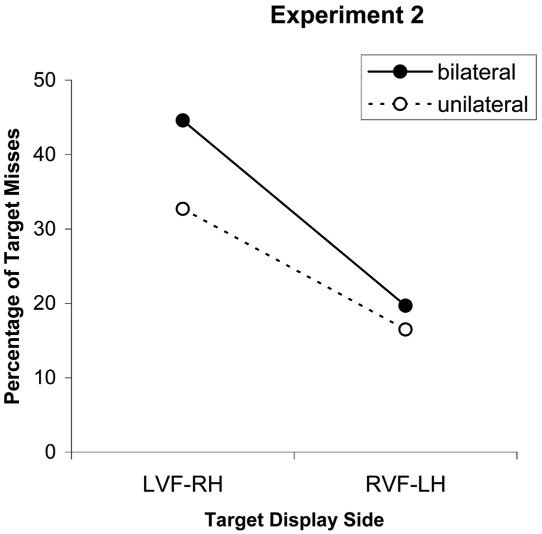

Figure 4. *Error rates (target misses) as a function of presentation condition in Experiment 2 with consonant strings as distractors.*

0.67 and 0.44 in the bilateral left and right display conditions, respectively, and 0.67 and 0.55 in the unilateral left and right display conditions, respectively. A one-way ANOVA revealed no effect of display condition ($F = 1.05$, $p = .38$), indicating that participants' response bias was not affected by the display condition.

Discussion

Experiment 2 was conducted to investigate the possibility that "neighbourless" consonant strings (e.g., xmxm) may produce just as much interference as do real words when projected to the LH. The findings confirm this. Participants found it much more difficult to recognize a target stimulus in the LVF−RH when a consonant string was simultaneously projected to the LH than they did in the unilateral condition when nothing was projected to the LH. In contrast, just as in Experiment 1, projecting a consonant string to the RH had no effect on participant's ability to recognize RVF−LH targets. These findings raise the possibility that the locus of the bottleneck giving rise to the interference effect is prelexical and strongly left lateralized.

Although we may tentatively conclude that the locus of the interference effect observed in Experiments 1 and 2 is prelexical, it is still not clear whether interference arises at the point of determining letter shapes or accessing abstract letter identities. One way to tease these two stages apart would be to use distractors that engage letter shape detection processes without engaging more abstract letter identification processes. To the extent that letter shape detection processes are carried out bilaterally (Dehaene et al., 2004; Miozzo & Caramazza, 1998), distractor stimuli that engage shape detection, but not letter identification, processes should produce the same amount of interference regardless of whether they appear in the left or right visual field. We explored this possibility in Experiment 4 by using distractors comprised of familiar symbols (e.g., <%∼^ +). Because these symbols are not constituent elements in letter strings, and because they do not map onto representations in the orthographic input lexicon, it follows that these symbols probably do not map onto abstract letter identities either. Yet, symbols of this type are familiar in reading contexts, and their shapes must be parsed in order to understand them. Hence, we reasoned that these symbols may engage the same shape detection processes that subserve reading processes. If we are correct in our speculation, and if it is the case that letter shape detection is supported by bilateral neural mechanisms, then symbol distractors (<#%∼^) should induce a symmetrical pattern of interference. We tested this possibility in Experiment 3.

EXPERIMENT 3

Experiment 3 was identical to Experiments 1 and 2, except that the distractors were replaced with strings of symbols (e.g., <#%∼^).

Method

Participants

Again, 14 undergraduates at Harvard University participated for either course credit or payment.

All participants were native speakers of English, had normal or corrected-to-normal vision, and were strongly right-handed (LQ: $M = .81$).

Materials

The materials were identical except that the distractor words were replaced with strings of symbols.

Results

The mean display duration across participants and test blocks was 119 ms. The mean rate of targets missed in the RVF (21.8%) was significantly less than the mean rate of missed targets in the LVF (40.4%): $F_1(1, 13) = 25.4, p < .01$; $F_2(1, 19) = 59.4, p < .01$. Likewise, there was a significant effect of display type, with more targets (33.7%) missed in the bilateral display condition than were missed in the unilateral display condition (28.4%): $F_1(1, 13) = 9.3, p = .01$; $F_2(1, 19) = 11.5, p < .01$. As can be seen in Figure 5, though, the nature of the main effect of display type in the present experiment is different from that obtained in Experiment 1 or Experiment 2. Namely, the amount of interference produced by symbol strings was similar in both visual fields. This is confirmed by the lack of a significant interaction between the factors of display type and visual field: $F_1(1, 13) = 1.7, p > .1$; $F_2(1, 19) < 1$.

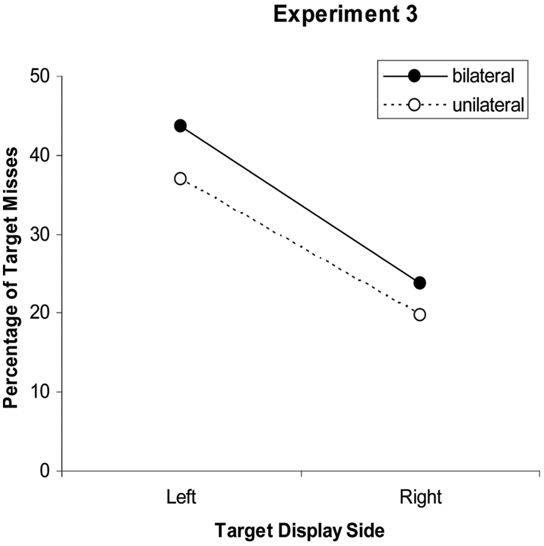

Figure 5. *Error rates (target misses) as a function of presentation condition in Experiment 3 with nonletter character strings (e.g., ^%~*) as distractors.*

The mean decision criterion statistic (Zc) was 0.56 and 0.41 in the bilateral left and right display conditions, respectively, and 0.60 and 0.50 in the unilateral left and right display conditions, respectively. A one-way ANOVA revealed no effect of display condition ($F < 1$), indicating that participants' response bias was not affected by the display condition.

Discussion

The results of Experiment 3 are important in two different ways. First, the finding that a string of familiar symbols (e.g., <#%~^) induces a similar amount of interference when projected to the left and right hemispheres suggests that the mechanism to which this interference effect should be attributed is distinct from the mechanism to which we attribute the interference effect induced by letter strings. Letter string distractors induce interference only when projected to the LH (Experiments 1 and 2); symbol string distractors induce a similar amount interference regardless of which hemisphere they are projected to. This finding is consistent with the proposal that (a) familiar symbols (e.g., <#%~^) engage letter shape detection processes without engaging abstract letter identification processes, and (b) shape detection processes are carried out by a bilaterally distributed mechanism.

The second way in which the results of Experiment 3 are important has to do with a possible alternative account of the findings reported in Experiments 1 and 2. According to this alternative account, the display type by visual field interaction observed in Experiments 1 and 2 is due to participants having a RVF attentional bias. That is, participants were less successful at recognizing a LVF target in the bilateral display condition because of a bias to attend to the RVF first; following from this proposal, the RVF distractor stimulus "captures" participants' attention, which makes it difficult to shift their attention to the LVF when the target is presented there. Of course, if this were the case, then any stimulus that is sufficiently distinct from the forward and backward masks to induce a reliable interference effect should lead to the same pattern of effects as that observed in Experiments 1 and 2. Yet the symbol strings in Experiment 3 were sufficiently salient to capture attention (they induced a significant cost) but they did not induce an asymmetrical pattern of interference. As such, it is highly unlikely that the display type by visual field interaction observed in Experiments 1 and 2 was due to a RVF attentional bias.

Another way in which the findings of Experiment 3 are important has to do with the possibility of a ceiling effect when targets are presented in the RVF but not in the LVF and, hence, the reason we observed a display type by visual field interaction in Experiments 1 and 2. The findings of Experiment 3 reveal that the unilateral right and the bilateral right conditions can be differentiated in this task, suggesting that there is nothing inherent to the task itself that precludes observing an effect of display type when targets appear in the RVF.

We have argued that the cost observed in Experiment 3 was due to interference at the stage of shape detection processes, which the familiar symbols that we used as distractors were effective in engaging. To confirm this, it is necessary to rule out the possibility that any stimulus will produce a small and symmetrical interference effect. We do this in Experiment 4 both with a very simple line drawing as a distractor (Experiment 4a) and with Chinese characters, which were unfamiliar to our participants (Experiment 4b).

EXPERIMENT 4

Experiments 4a and 4b were identical to the preceding experiments except that the letter string distractors were replaced with a line drawing () in Experiment 4a and Chinese characters (e.g., 饶 and 耤) in Experiment 4b.

Method

Participants

A total of 28 undergraduates at Harvard University participated for either course credit or payment, 14 in Experiment 4a and 14 in Experiment 4b. Once again, all participants were native speakers of English, had normal or corrected-to-normal vision, and were strongly right-handed (LQ: $M = .82$). None of the participants in Experiment 4b were proficient readers of Chinese characters.

Materials

The materials were identical to those used in Experiments 1 and 2 except for the distractors. In Experiment 4a, a line drawing was used as a distractor; in Experiment 4b, each distractor was replaced with one of 20 different Chinese characters, which were randomly assigned to the target/foil pairs.

Results

The mean display duration across the three test blocks was 118.8 ms in Experiment 4a and 163.8 ms in Experiment 4b. As can be seen in Figures 6 and 7, a very different pattern of results was obtained in Experiments 4a and 4b. Namely, distractors that were unfamiliar to our participants in a reading context were ineffective in inducing an interference effect. In fact, the only significant result in these two experiments was the main effect of visual field, which was significant in Experiment 4a, $F_1(1, 13) = 13.7$, $p < .01$; $F_2(1, 19) = 50.4$, $p < .01$, and Experiment 4b, $F_1(1, 13) = 56.1$, $p < .01$; $F_2(1, 19) = 82.5$, $p < .01$. In Experiment 4a, there was a significant effect of display type in the items analysis, $F_2(1, 19) = 6.2$, $p = .02$, but not in the subjects analysis ($F < 1$), and none of the other effects in either experiment, including the interactions, approached significance (all Fs < 1).

In Experiment 4a, the mean decision criterion statistic (Zc) was 0.46 and 0.51 in the bilateral left and right display conditions, respectively, and 0.42 and 0.51 in the unilateral left and right

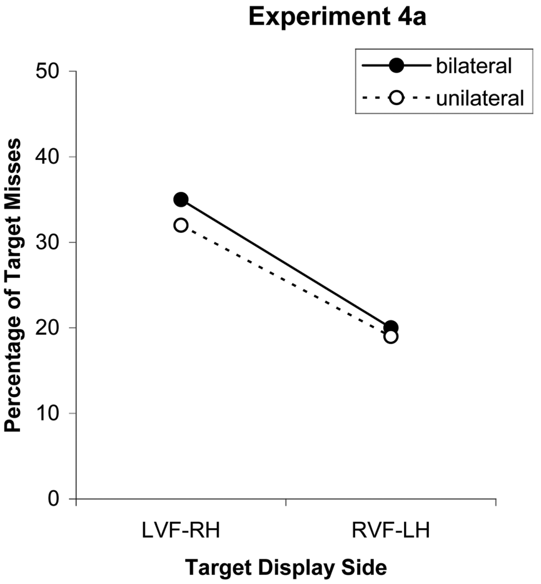

Figure 6. *Error rates (target misses) as a function of presentation condition in Experiment 4a with a line drawing as a distractor.*

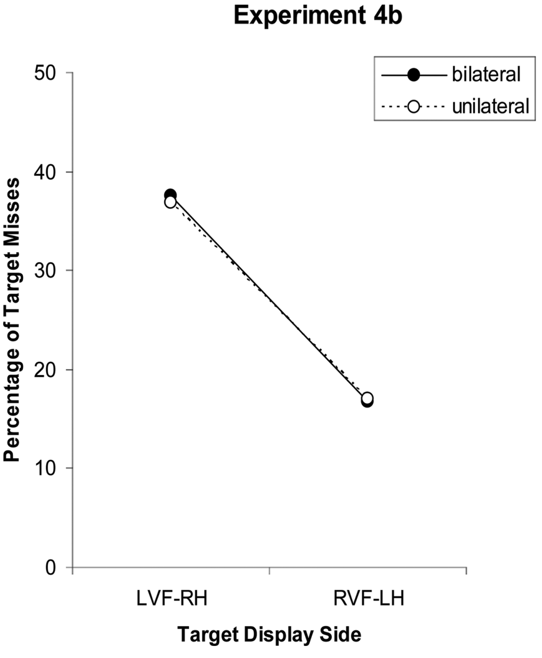

Figure 7. *Error rates (target misses) as a function of presentation condition in Experiment 4b with Chinese characters as distractors.*

display conditions, respectively. A one-way ANOVA revealed that participants' response bias was not affected by the display condition ($F < 1$). In Experiment 4b, Zc was calculated at 0.73 and 0.5 in the bilateral left and right display conditions, respectively, and 0.76 and 0.61 in the unilateral left and right conditions, respectively. Once again, a one-way ANOVA revealed that participants' response bias was not affected by the display condition ($F = 1.24$, $p = .31$).

Discussion

Experiment 4 was designed to address the possibility that the interference effect observed in Experiment 3 was not, as we argued, due to the engagement of shape detection processes by familiar symbols (e.g., <#%∼^) but, rather, to some general kind of interference that any distractor would be able to induce. The results of Experiments 4a and 4b reveal that the type of distractor that can induce interference in this paradigm is restricted to just those that engage reading processes, whether those be at the level of letter shape detection, abstract letter identification, or lexical access. Neither a simple line drawing nor highly complex logographs interfered significantly with the participants' word recognition task. We suggest that this is because these distractors were ineffective in engaging the reading process at any level of processing.

The findings of Experiment 4 are also important in confirming that the asymmetrical pattern of interference obtained in Experiments 1 and 2 was not due to a RVF attentional bias. If this were the case, it follows that any distractor should have been effective in "capturing" the attention of the participant and, hence, in inducing interference. The results of Experiments 3 and now 4 are clear in refuting this attentional bias account. Neither the familiar symbols used in Experiment 3 nor the line drawing used in Experiment 4a nor the Chinese characters used in Experiment 4b were effective in inducing the type of interference that letter strings induced.

Before concluding, we address one further concern with our interpretation of the results of

Experiments 1 and 2. We have argued that the locus of the interference effect produced by RVF letter string distractors is at the level of accessing abstract letter identities, yet our task involves word identification, not letter identification. As we pointed out above, though, the foils and the targets were selected to ensure that participants had to analyse the letter identities of each stimulus to perform the task (e.g., "goat" paired with the foil "boat"). As such, we suspect that the same effects as those obtained in Experiments 1 and 2 would be obtained in a straight letter identification task. We test this possibility in Experiment 5.

EXPERIMENT 5

In this experiment, participants ($N = 10$) were instructed to indicate when the target letter "f" was present. The target letter appeared in 5 different four-letter strings (e.g., xhfk). The position of the target letter was rotated through each position of each letter string for a total of 20 letter strings. The foil letter was "t", and foil letter strings were created in the same way as the target letter strings (see Appendix A). Using single letters as targets also allowed us to address the concern that the effects obtained in Experiments 1 through 4 were to do with differences in the distance from fixation for word-initial letters in the left and right visual fields. The initial letters of words appearing in the RVF were always closer to fixation than were the word-initial letters appearing in the LVF, and this may have contributed to the effects reported above in some way. We address this possibility in the present experiment insofar as single-letter targets allowed us to hold constant the distance from fixation to target in the left and right visual fields.

The procedure and design were identical to those in the experiments reported above.

Results

The mean target duration across the three test blocks was 198.7 ms. Just as in Experiments 1 and 2, main effects of visual field and display type were obtained. The mean rate of targets missed in the RVF (19.2%) was significantly less than the mean rate of targets missed in the LVF (39.1%): $F_1(1, 9) = 16.8$, $p < .01$; $F_2(1, 19) = 63.0$, $p < .01$. Likewise, there was a significant effect of display type, with more targets (32.7%) missed in the bilateral display condition than were missed in the unilateral display condition (25.6%): $F_1(1, 9) = 4.4$, $p = .06$; $F_2(1, 19) = 13.5$, $p < .01$. Also, just as in Experiments 1 and 2, the effect of display type is carried predominantly by the error rate in the bilateral left condition. This is confirmed by a significant interaction between the factors of display type and visual field: $F_1(1, 9) = 10.5$, $p = .01$; $F_2(1, 19) = 11.3$, $p < .01$. It is worth mentioning that 9 of the 10 participants exhibited this pattern of performance and that planned comparisons revealed a significant effect of display type for targets that appeared on the left, $F(1, 9) = 7.4$, $p = .02$, but not for targets that appeared on the right ($F < 1$).

A one-way ANOVA over the decision criterion statistic revealed a nonsignificant trend in the direction of participants adopting a more conservative response criterion when targets appeared in the left visual field ($F = 1.9$, $p = .14$; bilateral left, 0.52; bilateral right, 0.24; unilateral left, 0.49; unilateral right, 0.21). This was the only experiment that revealed such a trend. Importantly, there was no difference between the bilateral and unilateral left conditions.

Discussion

In a simple letter identification task (indicate when you see the letter "f"), consonant string distractors produced a large interference effect when projected to the left hemisphere but not when projected to the right hemisphere. These findings mirror those obtained in Experiments 1 and 2. The results of this experiment are important for two reasons. First, they confirm that the results obtained in Experiments 1 and 2 can be replicated when the target is a single letter (e.g., "f"), indicating that the interaction between display type and visual field is not exclusive to the word detection

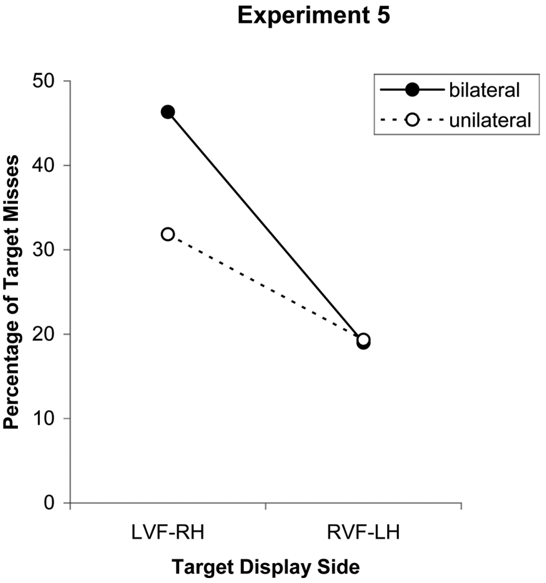

Figure 8. *Error rates (target misses) as a function of presentation condition in Experiment 5 in which participants indicated when the letter "f" was present. The letter "t" was used as a foil, and consonant strings were used as distractors.*

task. Second, these results allow us to rule out the possibility that the effects obtained in the word detection experiments were to do with differences in the relative distances between fixation and word initial letters for left- and right-visual-field words. In the present experiment, the use of single-letter targets allowed us to hold constant the distance between fixation and target in both visual fields. These findings, like those reported above, suggest that letter identification processes are limited in capacity and are strongly left lateralized. Below we discuss further the implications of these findings for localizing letter identification processes.

GENERAL DISCUSSION

The research reported here establishes several important findings. First, it was found that an individual's ability to recognize a target word is negatively affected by the presence of a contralateral distractor stimulus, but only when that distractor engages reading processes. For example, when the distractor stimuli were nonorthographic (i.e., a scribbled line) or logographic (i.e., Chinese characters, which our participants were unable to read), no interference was observed. In contrast, characters that are encountered while reading (e.g., ^%~*), and which presumably engage reading processes to some extent, were found to induce a small amount of interference. Letter strings (e.g., *model* or *xmxm*), regardless of their orthographic legality or number of orthographic neighbours, induced a highly significant interference effect. This finding is important because it reveals that the mechanisms subserving letter identification processes are limited in their capacity and, importantly, only become engaged by those stimuli with linguistic (orthographic) content.

The second important result reported here was the finding that distractor stimuli comprised of letter strings (e.g., xmxm), and familiar but nonletter characters (e.g., ^%~*#) induced a qualitatively different pattern of interference. This was confirmed in the three-way interaction between experiment, display type, and visual field, $F(1, 38) = 5.47$, $p = .03$. Nonletter distractors induced a small amount of interference regardless of whether they were presented in the right or left visual field. Letter strings (orthographically legal and illegal alike) induced much more interference, but, importantly, only when they appeared in the right visual field (i.e., projected to the left hemisphere). Letter strings had no appreciable effect when projected to the right hemisphere. We have suggested that nonletter distractors (e.g., ^%~*#) engage a bilaterally distributed mechanism responsible for detecting letter shapes—the first stage in the reading process. Similarly, we have suggested that the restriction of the interference effect for letter strings to the left hemisphere indicates that the processing of abstract letter identities—the second stage in the reading process—is strongly left lateralized.

Two important points are raised by these findings. The first of these has to do with letter strings inducing interference when projected to the left but not right hemisphere. The second has to do with the specificity of the left hemisphere response to the presence of orthographic content and the automaticity of that response. We discuss each of these points in turn.

Letter string distractors engage the left but not the right hemisphere

We began this article by reviewing recent neuroimaging studies of letter identification processes as well as findings from studies of reading performance in neuropsychological patients with pure alexia. These studies suggest that while very-low-level featural information is encoded in the RH (or, more precisely, the RH homologue of the VWFA), abstract letter identification processes are carried out exclusively in the VWFA (Chanoine et al., 1998; Dehaene et al., 2001, 2004; Miozzo & Caramazza, 1998). In addition to these studies, though, there is also evidence that in some cases the RH homologue is able to assume the functions of the VWFA when the LH is damaged (Cohen et al., 2004; Coltheart, 1980, 2000; Coslett & Monsul, 1994). The question pursued in this article concerned whether the RH is critical to letter identification processes in normal brains. Neuroimaging studies have not yet been able to answer this question definitively. The behavioural task used in the present study was designed to address this gap in the understanding of letter identification processes by determining the cost of engaging the RH when performing a simple reading task. The results were strikingly clear. Engaging the RH with a letter string had no effect at all on word recognition processes, whereas engaging the LH with a letter string had a robust and highly significant effect. Thus, insofar as the interference effect in this task may serve as a proxy of the extent to which a particular neural region is critical to abstract letter identification processes, we may conclude that the left hemisphere is critically involved in letter identification processes and that the right hemisphere is not. This finding converges well with the neuropsychological results reported by Chanoine et al. (1998) and Miozzo and Caramazza (1998) as well as with the neuroimaging results reported by Cohen et al. (2002, 2003, 2004) and Dehaene et al. (2004). Although future research using this particular paradigm in an fMRI experiment will be needed to determine what neural region within the left hemisphere was engaged by the letter string distractors, it seems reasonable, based upon the extant fMRI data, to speculate that it was the left fusiform.

Automatic engagement of the LH by orthographic distractors

Perhaps the most surprising and compelling result of this study is that the orthographically illegal distractors used in Experiment 2 (e.g., "xprg") were just as effective in disrupting the identification of target words as were the real words used in Experiment 1. This finding is compelling in several ways. First, it suggests that the locus of the interference effect is prelexical. Second, insofar as the mechanism engaged by these distractors constitutes a "bottleneck" in letter identification processes, we may conclude that these processes are limited in their capacity. Third, and perhaps most interesting, is the finding that this mechanism cannot help but become engaged by letter strings, regardless of their orthographic legality. In Experiments 2 and 5, the letter strings (e.g., *xprg*) were presented under heavily degraded conditions and had no inherent meaning, and yet even under these conditions letter strings, and only letter strings, induced a robust interference effect. This suggests that the processing of letter strings is carried out by a mechanism that cannot *not* be engaged when presented with stimuli possessing even a minimal amount of linguistic content. In this way, the finding reported here is very similar to the Stroop effect (Stroop, 1935; see MacLeod, 1991, for a review). The Stroop effect is characterized by the unavoidable engagement of the reading mechanism despite the task instructions to avoid reading the word and to name the ink colour of the written word. The findings reported here are very similar. Despite the instructions to indicate only the presence of an animal word (or the letter "f"; Experiment 5), the evidence suggests that letter identification processes were unavoidably engaged by stimuli possessing the barest amount of linguistic content. Taken together with the finding that letter strings only induced interference when projected to the left hemisphere, we may conclude that the processing of letter strings is subserved by an automatically engaged, capacity-limited, domain-specific, left-lateralized mechanism.

What "domain" does letter identification belong to? We began by stating that it is very unlikely that reading processes reflect the natural unfolding of a genetic programme and, hence, that they may be subserved by a domain-general cognitive mechanism. We also suggested that it would be just as reasonable to think that the language system may co-opt reading processes and, hence, that they may be subserved by a domain-specific mechanism. The results of the experiments reported here are quite compelling in suggesting that letter identification processes are subserved by a domain-specific mechanism. The letter identification mechanism, revealed to be the locus of the interference effect in this study, was found to be selectively engaged by letter strings, even when those strings were heavily degraded, had no inherent meaning, and failed to meet even basic orthographic constraints of English. This would suggest that the interference effect can be attributed to a mechanism that operates at a prelexical stage on the basis of bottom-up processes alone, a defining characteristic of "domain-specific" mechanisms. Note, though, that this does not necessarily mean that letter identification processes are left lateralized because they have been co-opted by a left-lateralized language system. The neural region within the left fusiform that is unavoidably engaged by letter strings may have evolved either phylogenetically or ontogenetically (or both) to respond to particular object shapes, and it just so happens that letters match onto these shapes. Another possibility has to do with the categorical status of abstract letter identities. It is well agreed upon that the left hemisphere is preferentially biased towards the processing of categorical information (Jager & Postma, 2003; Kosslyn et al., 1989; Laeng, Shah, & Kosslyn, 1999), and so, according to this possibility, it is not surprising to find that the letter identification process becomes restricted to the LH as processing progresses from early stages in which a highly variable input (letter shapes) is computed to later stages in which categorical elements (ALIs) are selected. In either case, it may be nothing more than coincidence that letter identification processes are left lateralized along with higher level language processes. Although the present research does not definitively speak to whether or not letter identification processes are domain specific because they have been co-opted by the language system, it is clear that letter identification processes are subserved by a domain-specific mechanism and that this mechanism is left lateralized in healthy right-handed individuals.

CONCLUSION

In a word recognition task (say yes if you see an animal word), in which a target (or foil) was presented in one visual field and a distractor stimulus in the other visual field, we observed two qualitatively distinct patterns of distractor-induced interference. Distractors composed of familiar symbols (e.g., \$*∼%^), which were thought to engage letter shape detection processes but not abstract letter identification processes, induced a small symmetrical interference effect across both hemispheres. Distractors composed of letter strings, on the other hand, induced a large interference effect, but only when projected to the left hemisphere. Neither orthographic legality nor number of orthographic neighbours was found to be an important factor in obtaining the left hemisphere interference effect. We suggest that while a bilaterally distributed mechanism is critically involved in shape detection, the mechanism that is critically involved in letter identification processes is strongly left lateralized in normal individuals. Thus we conclude that while the right hemisphere may be able to assume abstract letter identification processes in some brain-damaged individuals (Cohen et al., 2004; Coslett & Monsul, 1994), it does not play a critical role in normal letter identification processes.

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REFERENCES

Boles, D. (1990). What bilateral displays do. *Brain and Cognition*, *12*, 205–228.

Boles, D. (1994). An experimental comparison of stimulus type, display type, and input variable contributions to visual field asymmetry. *Brain and Cognition*, *24*, 184–197.

Caramazza, A., & Hillis, A. E. (1990). Levels of representation, coordinate frames, and unilateral neglect. *Cognitive Neuropsychology*, *7*, 381–445.

Chanoine, V., Teixeira Ferreira, C., Demonet, J. F., Nespoulous, J. L., & Poncet, M. (1998). Optic aphasia with pure alexia: A mild form of visual associative agnosia? A case study. *Cortex*, *34*, 437–448.

Chialant, D., & Caramazza, A. (1998). Perceptual and lexical factors in a case of letter-by-letter reading. *Cognitive Neuropsychology*, *15*, 167–201.

Cohen, L., Henry, C., Dehaene, S., Martinaud, O., Lehericy, S., Lemer C. et al. (2004). The pathophysiology of letter-by-letter reading. *Neuropsychologia*, *42*, 1768–1780.

Cohen, L., Lehericy, S., Chochon, F., Lemer, C. Rivaud, S., & Dehaene, S. (2002). Language-specific tuning of visual cortex? Functional properties of the visual word form area. *Brain*, *125*, 1054–1069.

Cohen, L., Martinaud, O., Lemer, C., Lehericy, S., Samson, Y., Obadia, M. et al. (2003). Visual word recognition in the left and right hemispheres: Anatomical and functional correlates of peripheral alexias. *Cerebral Cortex*, *13*, 1313–1333.

Coltheart, M. (1980). Deep dyslexia: A right hemisphere hypothesis. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge & Kegan Paul.

Coltheart, M. (2000). Deep dyslexia is right-hemisphere reading. *Brain and Language*, *71*, 299–309.

Coltheart, M., Davelaar, E., Jonasson, J. F., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535–555). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Coslett, H. B., & Monsul, N. (1994). Reading with the right hemisphere: Evidence from transcranial magnetic stimulation. *Brain and Language*, *46*, 198–211.

Coslett, H. B., & Saffran, E. M. (1989). Evidence for preserved reading in pure alexia. *Brain*, *112*, 327–329.

Coslett, H. B., & Saffran, E. M. (1992). Optic aphasia and the right hemisphere: A replication and extension. *Brain and Language*, *43*, 148–161.

Coslett, H. B., & Saffran, E. M. (1994). Mechanisms of implicit reading in pure alexia. In M. J. Farah & G. Ratcliff (Eds.), *The neuropsychology of high-level vision.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Davis, C. J. (2005). N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods*, *37*, 65–70.

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J.-B., Le Bihan, D. et al. (2004). Letter binding and the invariant recognition of masked words. *Psychological Science*, *15*, 307–313.

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*, *13*, 321–325.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J.-F., Poline, J.-B. et al. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, *4*, 752–758.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*, 116–124.

Haywood, M., & Coltheart, M. (2001). Neglect dyslexia with a stimulus-centred deficit and without visuospatial neglect. *Cognitive Neuropsychology*, *18*, 577–615.

Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: A review of the current evidence. *Neuropsychologia*, *41*, 504–515.

Knecht, S., Floel, A., Drager, B., Breitenstein, C., Sommer, J., Henningsen, H. et al. (2002). Degree of language lateralization determines susceptibility to unilateral brain lesions. *Nature Neuroscience*, *5*, 695–699.

Kosslyn, S. M., Koenig, O., Barrett, A., Cave, C., Tang, J., & Gabrieli, J. (1989). Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *Journal of Experimental Psychology: Perception and Performance*, *15*, 723–735.

Laeng, B., Shah, J., & Kosslyn, S. M. (1999). Identifying objects in conventional and contorted poses: Contributions of hemisphere-specific mechanisms. *Cognition*, *70*, 53–85.

Leiber, L. (1976). Lexical decisions in the left and right cerebral hemispheres. *Brain and Language*, *3*, 443–450.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163–203.

Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide*. Cambridge, UK: Cambridge University Press.

McCandliss, B., Cohen, L., & Dehaene, S. (2003). The visual word form area: Expertise for reading in the fusiform gyrus. *Trends in Cognitive Sciences*, *7*, 293–299.

Miozzo, M., & Caramazza, A. (1998). Varieties of pure alexia: The case of failure to access graphemic representations. *Cognitive Neuropsychology*, *15*, 203–238.

Perea, M., & Lupker, S. J. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: State of the art* (pp. 97–120). Hove, UK: Psychology Press.

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.

Price, C. J., & Devlin, J. T. (2003). The myth of the visual word form area. *Neuroimage*, *19*, 473–481.

Saffran, E., Bogyo, L. C., Schwartz, M. F., & Marin, O. S. M. (1980). Does deep dyslexia reflect right-hemisphere reading? In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge & Kegan Paul.

Saffran, E. M., & Coslett, H. B. (1998). Implicit vs. letter-by-letter reading in pure alexia: A tale of two systems. *Cognitive Neuropsychology*, *15*, 141–165.

Sorkin, R. D. (1999). Spreadsheet signal detection. *Behavior Research Methods, Instruments, & Computers*, *31*, 46–54.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Werker, J., & Tees, R. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior & Development*, *7*, 49–63.

Young, A. W., & Ellis, A. W. (1985). Different methods of lexical access for words presented in the left and right visual hemifields. *Brain and Language*, *24*, 326–358.

APPENDIX A

Experimental materials for Experiments 1–4

Experiments 1–4 stimuli						*Experiment 5 stimuli*		
Target	*Foil*	*Distractor*						
Exp. 1–4	*Exp. 1–4*	*Exp. 1*	*Exp. 2*	*Exp. 3*	*Exp. 4*	*Target*	*Foil*	*Distractor*
bear	pear	clue	xmxm	>&@ + %	饶	fxhk	txhk	pmpm
camel	canal	advise	cvcvc	%>&@ +	藉	fqzl	tqzl	pvpv
coyote	peyote	treaty	sdfsdf	+ %>&@	老	fzxh	tzxh	sgpz
donkey	turnkey	morale	nzcnzc	@ + %>&	梢	fvmj	tvmj	nzpn
eagle	finagle	lunar	rwxrxw	&@ + %>	京	fgkj	tgkj	rwpr
elephant	element	assign	wxghwlx	<% + @&	群	xfhk	xthk	wpgh
giraffe	piaffe	potato	pmtpmtp	% + @&<	诉	qfzl	qtzl	pmlp
goat	boat	flash	zxbz	+ @&<%	雄	zfxh	ztxh	zpbz
kangaroo	buckaroo	tent	bvxyvxyx	@&<% +	宣	vfmj	vtmj	bvpy
lizard	wizard	fatal	pzgpzg	&<% + @	酷	gfkj	gtkj	pzgp
monkey	flunkey	custom	ccwltw	$&@% +	饶	xhfk	xhtk	pwpw
mouse	blouse	herald	hchcx	&$% + @	淡	qzfl	qztl	hphp
penguin	gauguin	gloom	mfhdhf	+ %$	朵	zxfh	zxth	mlhg
leopard	shepard	crest	vhhxrb	@ + $%&	要	vmfj	vmtj	vhpr
raccoon	bassoon	whip	mttxvq	%&^%$	浑	gkfj	gktj	mlpv
seal	real	pray	rbvt	@$^%&	底	xhkf	xhkt	rbvl
sheep	sleep	duly	rlvrv	>@ +	厅	qzlf	qzlt	rvrv
squirrel	quarrel	silly	btbtbtbt	@%	明	zxhf	zxht	blbl
toad	load	opium	mfmf	*&%@$	陪	vmjf	vmjt	mlml
zebra	umbra	grey	dgdgd	>@%$@	握	gkjf	gkjt	dgdg