Deployment of spatial attention to words in central and peripheral vision

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Four perceptual identification experiments examined the influence of spatial cues on the recognition of words presented in central vision (with fixation on either the first or last letter of the target word) and in peripheral vision (displaced left or right of a central fixation point). Stimulus location had a strong effect on word identification accuracy in both central and peripheral vision, showing a strong right visual field superiority that did not depend on eccentricity. Valid spatial cues improved word identification for peripherally presented targets but were largely ineffective for centrally presented targets. Effects of spatial cuing interacted with visual field effects in Experiment 1, with valid cues reducing the right visual field superiority for peripherally located targets, but this interaction was shown to depend on the type of neutral cue. These results provide further support for the role of attentional factors in visual field asymmetries obtained with targets in peripheral vision but not with centrally presented targets.

Reading is a complex process that involves extracting visual information from a currently fixated word while simultaneously preparing to extract information from peripherally located words in the text. Therefore, apart from the basic processes involved in extracting information from foveated visual stimuli, reading also involves managing eye movements and attentional resources in order to optimize information extraction across foveal and parafoveal vision. The present study examines the extent to which the appropriate allocation of spatial attention can facilitate word recognition and whether or not the allocation depends on eccentricity. First we review the main findings from past research involving the key manipulations of the present study: the effects of visual field (VF), viewing position (VP), and spatial cuing on visual word recognition.

VF Effects

A standard finding in the literature on visual word recognition is that words presented to the right visual field (RVF) are easier to recognize than words presented to the left visual field (LVF) (Bouma, 1973; Bradshaw & Nettleton, 1983; Lindell & Nicholls, 2003; Mishkin & Forgays, 1952; Nicholls & Wood, 1998; Ortells, Tudela, Noguera, & Abad, 1998). RVF superiority is observed in experimental conditions whose stimulus exposures are brief enough to prevent eye movements to the stimulus location,¹ thus allowing researchers to rule out an explanation in terms of the speed with which a saccade can be planned and executed to the right as opposed to the left of fixation.

The prevailing interpretation of this RVF advantage is that it reflects cerebral asymmetries in the processing of written language and, in particular, that written language is processed more efficiently by the left cerebral hemi-

sphere (Bryden & Mondor, 1991). Given the structure of the visual system, RVF presentation provides direct access to the language centers located within the left hemisphere, whereas words presented in the LVF suffer from a processing delay equal to the time required to transmit information from the right to the left hemisphere (Kimura, 1966). Some initial support for this account was provided by the observation that left-lateralized subjects show a reduced RVF advantage (Brysbaert, 1994b; Hellige et al., 1994).

However, a popular alternative interpretation of VF asymmetries, one that is particularly relevant for the present study, is that they result from the manner in which spatial attention can be allocated across the VF (Kinsbourne, 1970; McCann, Folk, & Johnston, 1992; Mondor & Bryden, 1992; Nicholls & Wood, 1998; Ortells et al., 1998). According to this account, the RVF advantage would be caused by an attentional bias in favor of the RVF. This could result from scanning habits developed during the process of learning to read (Mishkin & Forgays, 1952). Key evidence in favor of this account was provided by Mishkin and Forgays, who showed that English words were better perceived in the RVF, whereas Yiddish words were better perceived in the LVF. However, other studies have found RVF advantages for languages read from right to left, and this has been taken as support for the hemispheric specialization account (Faust, Kravetz, & Babkoff, 1993; Melamed & Zaidel, 1993).²

Other authors have suggested that the asymmetry might be more perceptual than attentional, caused by an asymmetry in the availability of perceptual information to the right and left of fixation—that is, the perceptual span, which, for a language read from left to right, is approximately 4 characters to the left of fixation and 14 characters to

the right (Rayner, 1975). Thus, Pollatsek, Bolozky, Well, and Rayner (1981) demonstrated differences in perceptual span as a function of reading direction, with the span extending farther to the right for English (read from left to right) and farther to the left for Hebrew (read from right to left). In a similar vein, Nazir (2000, 2003) has suggested that low-level perceptual learning leads to the optimization of processing within the perceptual span (the area that must be visible in order for text reading to occur at normal speeds). In support of this approach, there is evidence that repeated presentation of a visual stimulus in the same region of the VF leads to enhanced discrimination of that stimulus at that particular location but not at other parts of the VF (Nazir & O'Regan, 1990). Furthermore, Nazir, Ben-Boutayab, Decoppet, Deutsch, and Frost (2004) have shown that VF differences in the perception of individual letters embedded in letter strings are constrained by reading direction (see also Lavidor & Whitney, 2005; Whitney & Lavidor, 2004).

VP Effects

Another asymmetry that is well documented in research on visual word recognition involves the effects of within-word fixation location. Varying fixation location within a word generates an inverse U-shaped function for recognition accuracy (U-shaped for latencies) as the fixation location moves from the first letter to the last letter of the word (Farid & Grainger, 1996; Nazir, O'Regan, & Jacobs, 1991; O'Regan & Jacobs, 1992; O'Regan, Lévy-Schoen, Pynte, & Brugailière, 1984; Vitu, O'Regan, & Mittau, 1990). In line with the visual hemifield studies summarized above, the VP function is asymmetric, with greater accuracy for fixation in the left part of the word (analogous to RVF presentation, and hence to the RVF superiority effect).

Theoretical accounts of the VP effect parallel accounts of VF asymmetries obtained with standard hemifield presentation. It is generally agreed that the major factor driving VP effects is the decrease in visual acuity as a function of distance from fixation, with letters viewed centrally benefiting from higher resolution than those further from fixation (Jacobs, 1979). However, accounts of the typical leftward asymmetry of the VP function (which cannot be accounted for in terms of acuity alone) are often expressed in terms of cerebral asymmetries (Brysbaert, 1994a, 2004; Brysbaert & d'Ydewalle, 1988; Brysbaert, Vitu, & Schroyens, 1996) or attentional/perceptual biases (see, e.g., Nazir, Jacobs, & O'Regan, 1998). As is the case for VF effects, perceptual biases may arise from perceptual learning (Nazir, 2000, 2003; Nazir et al., 2004). According to this account, optimal word recognition is obtained with eye fixation on the location in the word where the eyes prefer to land (i.e., between the beginning and the middle of the word) (Ducrot & Pynte, 2002; Rayner, 1979).

In line with the research on VF effects, the influence of reading direction on VP asymmetries has been particularly informative with respect to these two accounts (cerebral asymmetries vs. attentional/perceptual biases). According to the cerebral asymmetry account, reading direction should not influence the asymmetry, whereas according

to the asymmetric bias account, reading direction should change the direction of the asymmetry. Research aimed at addressing this critical point has compared VP functions obtained in languages read from left to right (such as English and French) with VP functions obtained in languages read from right to left (Arabic, Hebrew). At present, the results do not completely favor either of the above accounts, since it has been shown that the VP effects do indeed differ as a function of reading direction (contrary to the cerebral asymmetry account) but are not completely reversed (as predicted by the asymmetric attentional/perceptual bias account). Thus, it has been found that the VP curve is more symmetric for languages read from right to left (Deutsch & Rayner, 1999; Farid & Grainger, 1996; Nazir et al., 2004) than for languages read from left to right (see, e.g., O'Regan & Jacobs, 1992; O'Regan et al., 1984; Stevens & Grainger, 2003).

This evidence thus suggests that the asymmetric form of the VP function, repeatedly observed in languages read from left to right, is not the result of one or the other of the two mechanisms described above (cerebral asymmetry, attentional/perceptual biases). The asymmetry could result from a combined influence of the two or from the operation of another mechanism. One possible additional mechanism concerns how information is distributed across printed words. In languages like English and French, for example, word beginnings are more informative than word endings. Knowing the first letters of a word typically provides more constraint on possible word identity than knowing the final letters of a word. Several authors have proposed this as a central mechanism, combined with variations in letter visibility as a function of visual acuity, in accounting for the asymmetric form of the VP function (Brysbaert et al., 1996; Clark & O'Regan, 1999; O'Regan et al., 1984; Stevens & Grainger, 2003). In line with this idea, O'Regan et al. showed that when a word is more highly constrained by its ending than by its beginning, then fixating toward the beginning of such words confers less of an advantage than it does with words that are highly constrained by their beginning letters (see also Holmes & O'Regan, 1987, for comparable results).³

Most relevant to the present study is the work of Brysbaert et al. (1996), which demonstrated a strong relation between the VP effect (varying within-word fixation position) and VF effects (with fixation outside the word). By manipulating, in the same study, both within-word fixation position and fixation position outside the word, Brysbaert et al. observed a continuous VP function that took the shape of a Gaussian distribution with the mode placed left of stimulus center. Brysbaert et al.'s study therefore suggests that there is nothing fundamentally different about recognizing a word when fixating its extremities compared with recognizing a word that is completely displaced relative to fixation. These authors argued that there is no fundamental difference between foveal and parafoveal vision and that common mechanisms (one of which is hemispheric specialization) underlie both the RVF advantage in parafoveal word recognition and the off-center VP function in foveal word recognition (see also Brysbaert, 1994a, for similar findings).

Spatial Attention and Word Recognition

As shown above, divided VF research suggests that attentional factors may contribute to the RVF superiority for language processing. The classic paradigm for investigating attentional influences on stimulus detection and recognition is the Posner cuing paradigm (Posner, 1980). Attention is directed to a particular spatial location either by some centrally located cue (e.g., an arrow pointing right or left, called an endogenous cue) or by the brief appearance of a stimulus at a specific location (an exogenous cue). With appropriate stimulus presentation conditions (i.e., timing and position of cues and targets), stimuli that appear in the cued location (the valid cue condition) are typically processed more efficiently than when there is no spatial cue (the neutral condition). Furthermore, a cost in processing is observed when a stimulus appears in a location different from one that has just been cued (the invalid cue condition). Improved performance in the presence of valid cues is commonly interpreted as the result of a movement of spatial attention induced by the cue (Posner, 1988) or as a change in the distribution of the attentional gradient at the cued location (LaBerge & Brown, 1989).

Several studies have reported improved word recognition in the presence of valid spatial cues in different variations of the Posner cuing paradigm (see, e.g., Gatheron & Siéroff, 1999; McCann et al., 1992; Mondor & Bryden, 1992; Siéroff & Posner, 1988). For example, by using a peripheral cuing procedure in a cost–benefit paradigm that included both valid and invalid trials, McCann et al. found reliable attentional effects on lexical decision performance on word and nonword targets displaced vertically with respect to fixation.

There is evidence that effects of spatial cuing interact with effects of VF. For example, in Mondor and Bryden's third experiment in their 1992 study, the position of a lateralized target was indicated by a peripheral cue (100% valid), and the cue–target stimulus onset asynchrony (SOA) was varied to manipulate the amount of time available for moving attention. They found that the RVF advantage for words and nonwords at a 0-msec SOA was reliably attenuated at a 50-msec SOA, thus showing that lexical decision performance can be notably influenced by attentional factors. Using the standard Posner exogenous cuing procedure, Nicholls and Wood (1998) found that cuing effects were robust only for stimuli presented to the LVF and not to the RVF. In this study, the presence of a valid spatial cue reduced the size of the RVF superiority. In a very similar experiment (the difference being that it used lexical decision rather than word naming, as the Nicholls & Wood study did), Ortells et al. (1998, Experiment 6) reported no interaction between exogenous cuing effects and VF. However, an inspection of the results of Ortells et al. shows that VF effects were numerically much smaller in the presence of a valid spatial cue, suggesting that a valid spatial cue had (at least numerically) reduced the RVF advantage. Using a beginning/end cuing procedure, Lindell and Nicholls (2003) also obtained a differential cuing effect with four-letter words presented in the LVF and RVF. Responses to RVF presentations were equally efficient regardless of whether they were preceded

by a cue located at the beginning of the upcoming target word, at the end of the target word, or by a neutral cue. In contrast, responses to LVF presentations showed a facilitatory effect of beginning cue, which drew spatial attention to the initial letter cluster. Once again, this finding is in line with Nicholls and Wood's research indicating an enhanced effect of valid cues on LVF trials (see also Gatheron & Siéroff, 1999).

If the RVF advantage is at least partly caused by an attentional bias to the right of fixation, then it makes sense that this bias could be corrected by attracting attention to the LVF. In order to explain the above pattern of effects, one has only to assume that combining an RVF cue with an RVF bias would generate a smaller gain than one would get using an LVF cue to counter the RVF bias. Since attention is already principally directed toward the RVF, the effects of an RVF spatial cue could be attenuated by a ceiling effect (i.e., the amount of attention that can be directed to a given part of space at a given time has a maximum). In line with this account, it should be noted that Nicholls and Wood (1998) also tested an invalid cue condition and found that the RVF advantage was greatly increased in this condition. For RVF stimuli, the invalid cue was counteracted by an RVF bias to cause a small processing cost relative to the neutral cue condition. On the other hand, for LVF stimuli, the invalid cue combined with an RVF bias to cause a much larger cost in processing relative to a neutral cue.

Finally, all of the above-cited studies used a peripheral cuing procedure with targets appearing in RVF or LVF. Auclair and Siéroff (2002), however, used a beginning/end cuing procedure with foveally presented targets. In this study, single digit cues were used to attract attention to the beginning (left side) or end (right side) of centrally fixated word and nonword stimuli. Auclair and Siéroff found an interaction between cue validity and the familiarity of the letter string, with nonwords being more sensitive to cue type than were words. In particular, the identification of the initial three letters of centrally presented nonwords was facilitated by an LVF but not an RVF cue, whereas identification of the final three letters was facilitated by an RVF but not an LVF cue. A cuing effect was also obtained with words presented in conditions that lowered the level of performance either by increasing length (10-letter words) or reducing exposure duration (17 msec). These results are compatible with an early role of spatial attention in letter string processing, but they also show that the lexical status of a letter string can directly influence the distribution of attention before identification processes are achieved.⁴

The Present Study

This literature review has shown that attentional biases may partly underlie effects of VF and VP on visual word recognition. Furthermore, evidence that there is an early involvement of attentional mechanisms in word recognition and that these mechanisms may interact with VF provides support for the role of attention as a unifying explanation for these different phenomena. The present study provides a further contribution to the study of attentional influences

Figure 1. Description of the procedure used in Experiment 1.

on VF effects in visual word recognition. We chose to use a perceptual identification paradigm in order to increase the size of the RVF advantage compared with the size of VF effects found in other tasks and thus to increase the possibility of observing a modulation of this advantage by spatial cues. Prior research has also shown that the perceptual identification task is more sensitive to effects of within-word fixation position than other tasks typically used in word recognition research (e.g., lexical decision, naming). We also examined the influence of spatial cues on the asymmetric effects of within-word fixations.

In the present study, visually presented target words appeared left or right of a central fixation point. In one condition (central presentation, Experiments 2 and 4), fixation was on the first or the last letter of the word, and in the other condition (peripheral presentation, Experiments 1 and 3), words were displaced 2.13° left or right of the central fixation point (see Figure 1). On half of the trials, the location of the word target was indicated by a string of hash marks presented briefly before the word (valid cue), and on the remaining trials, the hash marks covered both possible locations of the target (neutral cue).

Attentional biases offer one common interpretation for both VF asymmetries and within-word VP asymmetries. In both conditions, fixations to the left of the center of a word are less damaging than fixations to the right of a word's center, because people trained to read from left to right can allocate their attention more rapidly and effectively to the right than to the left. The present study puts this account to test on two grounds: (1) If the observed asymmetries in word recognition as a function of stimulus position are due at least partly to attentional biases, then we expect to be able to modulate these effects with the use of spatial cues. (2) If attentional biases represent one significant component of both VF asymmetries and the asymmetric VP function, then it should be possible to

modify both of these effects in a similar way with the same attentional manipulation.

EXPERIMENT 1

The purpose of this experiment was to investigate spatial cuing effects on word identification accuracy to words presented to the LVF and RVF in peripheral vision.

Method

Participants. Forty students (38 females and 2 males, mean age 20.1 years) from the University of Provence volunteered to participate; 2 were left-handed. All were native speakers of French and reported normal or corrected-to-normal vision.

Design and Stimuli. The stimulus display for the valid and neutral trials is illustrated in Figure 1. A total of 200 eight-letter target words were used. Half of the words were low frequency (LF)—that is, having a mean printed frequency of less than three occurrences per million (New, Pallier, Ferrand, & Matos, 2001)—and the other half were high frequency (HF), with a mean printed frequency greater than 33 occurrences per million. In each frequency set, 84% of the words were nouns, 9% were verbs, and 7% were adjectives. The orthographic regularity of the trigrams in the words was also controlled (Content & Radeau, 1988). These target words were presented at a distance of 2.13° to the left or right of a central fixation cross (LVF or RVF). The peripheral cue consisted of a string of eight hash marks (#####), presented such that the inner edge of the cue was displaced 2.13° horizontally from the central fixation cross (i.e., at the same eccentricity as word stimuli). On valid trials, the string of hash marks appeared either to the left or right of the central fixation cross, coinciding with the subsequent position of the target word (LVF or RVF). On neutral trials, the string of hash marks appeared on both sides of the fixation cross and therefore gave no information concerning the position of the upcoming target word.

The testing session was divided into two presentation conditions: one in which valid and neutral trials were randomized for each participant and the other in which valid and neutral trials were presented in two separate blocks. In the first condition, participants could not guess in advance the type of cue (mixed-cues condition). In the second condition, participants knew in advance what type

of cue would be presented in each block (blocked-cue condition); in this condition, the order of the two blocks was counterbalanced across participants. Therefore, Experiment 1 manipulated cue validity (valid vs. neutral), VF (LVF vs. RVF), word frequency (HF vs. LF), and cue blocking (blocked vs. mixed) in a $2 \times 2 \times 2 \times 2$ factorial design. All factors except cue presentation condition were manipulated within participants.

Apparatus and Procedure. Participants were tested individually. Stimulus presentation was on a 15-in. color monitor connected to a Pentium III PC computer running the DMDX software package version 2.9.01 (Forster & Forster, 2001). The stimuli were displayed in lowercase white letters on a black background in 12-point Courier New font. Participants were seated 50 cm from the screen. At this distance, each letter string subtended 4.25° of visual angle. Each trial consisted of the following sequence of events (see Figure 1). At the beginning of each trial, participants had to fixate the fixation cross displayed in the middle of the screen without moving their eyes. The importance of maintaining eye fixation on this point was repeatedly stressed. Then, 500 msec later, a spatial cue (string of hash marks) appeared laterally for 50 msec. After a 30-msec delay, the word was presented for 80 msec, to the left or right of the fixation point. The total elapsed time between the onset of the cue and the offset of the target thus was 160 msec—brief enough to discourage eye movements. The participant's task was to indicate which word she or he had seen by typing the corresponding word on the computer keyboard. If that was not possible, participants were asked to type as many letters as they could. After participants had typed their response and confirmed by pressing the Enter key, the screen was cleared and, after a 500-msec delay, a new trial began. A 12-item practice session was held in advance, followed by a single experimental block of 200 trials (mixed-cues condition) or by two experimental blocks of 100 trials each (blocked-cues condition).

Results and Discussion

In this and the following experiments, an ANOVA was performed on the percentage of correct word identifications per condition and participant with VF (LVF vs. RVF), cue validity (valid vs. neutral), cue blocking (blocked vs. mixed), and word frequency as factors. Only completely correct reports of word identity were included in the analysis. The results of Experiment 1 are summarized in Table 1.

The ANOVA revealed a main effect of word frequency [$F(1,38) = 49.47, p < .0001$] with 58.27% identification for HF words and 50.95% for LF words. A significant main effect of visual field was also obtained [$F(1,38) = 49.604, p < .0001$]. Word identifications for trials presented to the RVF were 20.62% higher on average than those for trials presented to the LVF. There was also a main effect of cue validity [$F(1,38) = 219.94, p < .0001$], showing that words with valid cues were better identified than those with neutral cues (VC = 71.22%; NC = 38%). There was no effect of cue blocking ($F < 1$; 53.65% vs. 55.57% for mixed- and blocked-cues conditions, respectively).

Figure 2. Percentage of correct word identifications as a function of VF and cue validity in Experiment 1. (Here and in Figures 4, 6, and 7: VC, valid cue; NC, neutral cue; VF, visual field; LVF, left VF; RVF, right VF.)

As Figure 2 shows, there was a stronger cuing effect for the LVF [$F(1,38) = 185.28, p < .0001$] than for the RVF [$F(1,38) = 104.77, p < .0001$], and this produced a significant interaction between the effects of VF and cue validity [$F(1,38) = 5.64, p < .023$]. This interaction also indicates that in conditions with a valid spatial cue, the RVF advantage was reduced [$F(1,38) = 32.81, p < .0001$] compared with conditions with a neutral cue [$F(1,38) = 82.56, p < .0001$]. No other interaction approached statistical significance.

The results of Experiment 1 are clear-cut. We replicated the standard RVF advantage in visual word recognition for languages with scripts that are read from left to right, and we replicated the standard advantage for valid cues versus neutral cues using an exogenous spatial cuing procedure. Most important, however, is the finding that spatial cues modulated the VF effect, with valid cues reducing the LVF disadvantage. This result is in line with results reported by Nicholls and Wood (1998). As expected, we have successfully increased the overall size of the RVF advantage in our perceptual identification task (compared with the naming task used by Nicholls and Wood), and the increased sensitivity of our dependent measure now reveals a significant interaction between VF differences

Table 1
Percentage of Correct Word Identifications As a Function of Cue Validity, Word Frequency, and Visual Field in Experiment 1

	Mixed-Cues Condition								Blocked-Cues Condition							
	LVF				RVF				LVF				RVF			
	HF	SD	LF	SD	HF	SD	LF	SD	HF	SD	LF	SD	HF	SD	LF	SD
Neutral cue	29.80	19.40	22.80	15.36	52.40	18.53	43.20	17.63	28.40	18.58	20.40	14.50	58.80	21.25	48.20	19.87
Valid cue	68.40	22.99	58.20	24.67	78.20	14.42	76.20	16.94	66.40	18.46	60.00	20.10	83.80	10.01	78.60	13.50

Note—LVF, left visual field; RVF, right visual field; HF, high frequency; LF, low frequency.

Figure 3. Description of the procedure used in Experiment 2.

and spatial cuing. This is in line with the hypothesis that at least part of the RVF advantage results from a preference for attentional allocation to the right of fixation (at least with printed verbal material).

EXPERIMENT 2

Experiment 2 followed the same procedure used in Experiment 1, except that within-word fixations and lower levels of eccentricity were used. Words were presented with either their first letter (RVF presentation) or their last letter (LVF presentation) on the central fixation point. Pilot work in our laboratory had suggested that this change in eccentricity would be sufficient to remove all influence of spatial cuing.⁵

Method

Participants. Forty students (4 males and 26 females) from the University of Provence volunteered to participate. Their mean age was 24.2 years and all reported normal or corrected-to-normal visual acuity. Five were left-handed. All were native speakers of French and none had participated in Experiment 1.

Design and Stimuli. The design and stimuli were the same used in Experiment 1, except that the target words were presented foveally with either their first letter (RVF presentation) or their last letter (LVF presentation) on the central fixation point. The neutral cue therefore consisted of a continuous string of 16 hash marks twice the

length of the target word, instead of two separate strings of 8 hash marks as in Experiment 1.

Apparatus and Procedure. The apparatus and procedure were the same as in Experiment 1 with the following exceptions: (1) Stimulus presentation duration was reduced in order to keep performance at approximately the same level as in Experiment 1 (50 msec vs. 80 msec in Experiment 1), and (2) to avoid additional masking, the central fixation cross was replaced with two vertically aligned central fixation lines with a gap between them (see Figure 3). Participants were instructed to fixate the gap.

Results and Discussion

Percentages of correct word identifications per condition are shown in Table 2. The ANOVA revealed a large (12%) frequency effect [$F(1,38) = 208.88, p < .0001$]. In addition, there was a main effect of VF [$F(1,38) = 153.20, p < .0001$], reflecting the fact that the accuracy of reports was better in the RVF ($M = 85.82\%$) than in the LVF ($M = 55.40\%$). There was also a significant main effect of cue validity [$F(1,38) = 4.30, p = .045$]. As Figure 4 shows, this effect reflects a slightly better performance on valid trials ($M = 71.45\%$) than on neutral trials ($M = 69.77\%$). Note, however, that this cuing effect is much less pronounced than in Experiment 1 (33.22% vs. 1.68% for Experiments 1 and 2, respectively). There was no hint of an interaction between cue type and side of presentation ($F < 1$). The effect of cue blocking was not

Table 2
Percentage of Correct Word Identifications As a Function of Cue Validity, Word Frequency, and Visual Field in Experiment 2

	Mixed-Cues Condition								Blocked-Cues Condition							
	LVF				RVF				LVF				RVF			
	HF	SD	LF	SD	HF	SD	LF	SD	HF	SD	LF	SD	HF	SD	LF	SD
Neutral cue	57.80	19.18	45.20	18.13	90.60	7.23	77.60	12.47	64.80	18.70	50.40	19.44	90.00	8.75	81.80	12.41
Valid cue	60.60	19.82	47.20	19.14	88.40	7.33	81.40	10.49	67.00	18.02	50.20	21.89	93.00	6.73	83.80	11.71

Note—LVF, left visual field; RVF, right visual field; HF, high frequency; LF, low frequency.

Figure 4. Percentage of correct word identifications as a function of VF and cue validity in Experiment 2.

significant [$F(1,38) = 1.29$, n.s.], and this factor did not interact with the other factors (all F s < 1). There was a significant VF $\times$ word frequency interaction [$F(1,38) = 6.99$, $p = .012$], with a stronger word frequency effect in the LVF ($M = 13.4\%$) than in the RVF ($M = 9.3\%$). Pairwise comparisons revealed a significant difference between HF and LF words in both VFs [$F(1,38) = 116.68$, $p < .0001$, for the LVF and $F(1,38) = 49.88$, $p < .0001$, for the RVF]. This interaction also indicates that the RVF advantage was reduced for HF words [$F(1,38) = 222.88$, $p < .0001$] compared with LF words [$F(1,38) = 308.82$, $p < .0001$].

As Figure 4 demonstrates, the effects of spatial cuing have been drastically reduced in Experiment 2. On the other hand, we still observe the standard RVF superiority in word recognition, with about the same amplitude as in Experiment 1 (30% vs. 21% in Experiment 1). Spatial cuing did not influence the effects of VF in Experiment 2. This pattern of results resembles that found by Auclair and Siéroff (2002) with foveally presented targets. Remember that in their experiments, a cuing effect was shown for six-letter and eight-letter pseudowords, whereas no cuing effect was observed for words of that length.

However, Experiment 2 differed from Experiment 1 in terms of the type of mask used in the neutral cue condition.

In Experiment 1, the neutral cue consisted of two separate series of hash marks the same length as the target words, whereas in Experiment 2, the neutral cue was formed of a continuous series of hash marks twice the length of target words (see Figures 1 and 3). Experiment 3 was designed to check whether or not the continuous/discontinuous nature of the neutral cuing stimulus might be the source of the difference in cuing effects observed in Experiments 1 and 2.

EXPERIMENT 3

Experiment 3 followed the same procedure used in Experiment 1, except that a large continuous mask, rather than two distinct masking patterns, was used in the neutral cue condition.

Method

Participants. Twenty students (18 females and 2 males) from the University of Provence volunteered to participate. Their mean age was 24.1 years, and 1 was left-handed. All were native speakers of French and reported normal or corrected-to-normal vision. None had participated in the prior experiments.

Design, Stimuli, Apparatus, and Procedure. The design, stimuli, apparatus, and procedure were the same as those in Experiment 1 except for the following: (1) The two distinct strings of hash marks were replaced by a continuous string of 24 hash marks, and (2) only the mixed-cues presentation condition was used in Experiment 3 since cue blocking did not significantly affect performance in Experiments 1 and 2 (F s < 1)⁶ (see Figure 5).

Results and Discussion

The mean percentages of correct identification scores per condition are presented in Table 3. As in our previous experiments, word frequency generated a significant main effect [$F(1,19) = 42.92$, $p < .0001$], with better performance on HF words ($M = 53.50\%$) than on LF words ($M = 44.80\%$). There was also a clear RVF advantage [$F(1,19) = 30.29$, $p < .0001$], with 39.40% identification for the LVF and 58.90% for the RVF, and a main effect of cue validity [$F(1,19) = 177.42$, $p < .0001$], showing that words with valid cues were identified better than those with neutral cues (VC = 68.25%; NC = 29.45%). There were no significant interactions (all F s < 1).

The presence of a strong cuing effect in Experiment 3 allows us to rule out the nature of the neutral cue stimulus as the source of the difference in cuing effects across Experiments 1 and 2; had it been, we would have expected to obtain much reduced effects of cuing in Experiment 3 compared with Experiment 1, but this was clearly not the case. Thus, we can tentatively conclude that target word

Table 3
Percentage of Correct Word Identifications As a Function of Cue Validity, Word Frequency, and Visual Field in Experiment 3

	LVF				RVF			
	HF	SD	LF	SD	HF	SD	LF	SD
Neutral cue	22.80	11.47	15.60	10.29	45.20	18.13	34.20	15.60
Valid cue	63.40	16.01	55.80	20.29	82.60	13.50	73.60	14.06

Note—LVF, left visual field; RVF, right visual field; HF, high frequency; LF, low frequency.

		Valid Trials	Neutral Trials
Fixation Point	500 msec
Spatial Cue	50 msec
Delay	30 msec
Target Word	80 msec
Answer

Figure 5. Description of the procedure used in Experiment 3.

eccentricity was the critical factor driving the reduction of cuing effects found in Experiment 2.

Unlike in Experiment 1, the interaction between cuing and VF was not significant in Experiment 3. A comparison of Figures 2 and 6 shows that the neutral cue condition has changed across experiments. This was to be expected, given that the only difference between Experiments 1 and 3 was the nature of the neutral cue stimulus (two separate strings of hash marks in Experiment 1 vs. one long string of hash marks in Experiment 3). The type of neutral cue used in Experiment 3 reduced the RVF advantage obtained in the neutral cue condition. This can be taken as further evidence that attentional biases within a continuous string of letters or characters are not as strong as those that operate across clearly distinct spatial locations.

Although stimulus presentation duration had been reduced in Experiment 2 compared with the duration thereof in both Experiments 1 and 3, performance was overall better in Experiment 2 than in the other two experiments. Thus, it is still possible that the superior performance of participants in Experiment 2 might be the reason for the smaller cuing effects that were observed.

EXPERIMENT 4

Experiment 4 followed the same procedure used in Experiment 2 but with a shorter stimulus exposure.

Method

Participants. Twenty students (18 females and 2 males) from the University of Provence volunteered to participate. Their mean age was 23.2 years, all reported having normal or corrected-to-normal visual acuity, and two were left-handed. All were native speakers of French and none had participated in any of the prior experiments.

Design, Stimuli, Apparatus, and Procedure. The design, stimuli, apparatus, and procedure were the same as those used in Experiment 2. The target words were presented foveally, with either their

first letter (RVF presentation) or their last letter (LVF presentation) on the central fixation point. The only difference was that stimulus presentation duration was reduced in order to keep performance at approximately the same level as in Experiments 1 and 3 (27-msec stimulus exposure in Experiment 4 vs. 50 msec in Experiment 2). Furthermore, as in the previous experiment, only the mixed-cues presentation condition was used.

Results and Discussion

The percentages of correct identification scores are shown in Table 4. As expected, the ANOVA revealed a large (12.3%) frequency effect [$F(1,19) = 87.34$, $p < .0001$]. There was also a main effect of VF [$F(1,19) =$

Figure 6. Percentage of correct word identifications as a function of VF and cue validity in Experiment 3.

Table 4
Percentage of Correct Word Identifications As a Function of Cue Validity,
Word Frequency, and Visual Field in Experiment 4

	LVF				RVF			
	HF	SD	LF	SD	HF	SD	LF	SD
Neutral cue	50.00	23.31	33.00	17.65	83.40	12.47	71.40	17.28
Valid cue	48.40	17.84	34.80	18.36	79.20	16.03	72.60	16.38

Note—LVF, left visual field; RVF, right visual field; HF, high frequency; LF, low frequency.

64.88, $p < .0001$]. Mean percentage of correct word identification was 41.5% for the LVF and 76.65% for the RVF (see Figure 7). However, neither the main effect of cue validity nor the interaction between cue validity and VF was significant ($F_s < 1$).

As in Experiment 2, the ANOVA revealed an interaction between VF and word frequency [$F(1,19) = 5.03$, $p = .037$]. As Table 2 shows, the difference between HF and LF words was more pronounced in the LVF than in the RVF. The effects of word frequency were, however, significant in both the LVF [$F(1,19) = 32.70$, $p < .001$] and the RVF [$F(1,19) = 12.08$, $p = .003$]. Again, it appears that with fixations on either the first or the last letter of a word, the RVF advantage is reduced in HF words [$F(1,19) = 143.95$, $p < .0001$] compared with LF words [$F(1,19) = 202.80$, $p < .0001$].

The results of Experiment 4 are clear-cut. In conditions in which average performance was in line with that of Experiments 1 and 3, there was absolutely no effect of spatial cuing on visual word recognition. In order to provide a statistical evaluation of the observed differences in effects of cue validity as a function of target word eccentricity, we performed a combined analysis of Experiments 1–4.

CROSS-EXPERIMENT ANALYSES

A complementary analysis combining Experiments 1 and 3 (peripheral presentation of target words; see Figures 1 and 5) and Experiments 2 and 4 (central presentation of target words; see Figure 3) was carried out. The accuracy data were submitted to an ANOVA with one between-participants factor (eccentricity, central vs. peripheral presentation of target words) and three within-participants factors (VF, LVF vs. RVF; word frequency, high vs. low; and cue validity, valid vs. neutral). A significant interaction between eccentricity and cue validity was obtained [$F(1,78) = 228.97$, $p < .0001$]. This provides statistical support for the observation that effects of cue validity were much less pronounced in the central presentation conditions (Experiments 1 and 3; $M = 0.45\%$) than in the peripheral presentation conditions (Experiments 2 and 4; $M = 36.3\%$). This result suggests that reallocation of attention away from a central fixation point is necessary only above a certain level of eccentricity. Before that level of eccentricity is attained, it appears that participants can spread attention across a wide enough area to process with equal ease all targets that fall within that area.

The combined ANOVA also revealed a significant interaction between eccentricity and word frequency

[$F(1,78) = 8.93$, $p = .0038$], which corresponds to the fact that the difference between HF and LF words was more pronounced for centrally presented targets [$F(1,39) = 181.43$, $p < .0001$] than for peripheral targets [$F(1,39) = 61.71$, $p < .0001$]. In line with this, although the eccentricity $\times$ word frequency $\times$ VF interaction did not reach significance [$F(1,78) = 2.32$, $p = .13$], there was a significant partial interaction between word frequency and VF for central presentation [$F(1,39) = 5.25$, $p = .027$], reflecting the fact that the frequency effect was greater in the LVF than in the RVF; there was no interaction for peripheral presentation conditions ($F < 1$). Thus, word frequency only modulated the effects of VF in the central presentation conditions of Experiments 2 and 4. There was no interaction between eccentricity and VF ($F < 1$).

GENERAL DISCUSSION

The present study investigated spatial cuing effects on word identification accuracy for words presented in the LVF and RVF in either central or peripheral vision. The standard cuing effect was observed for peripheral vision, accompanied by a standard RVF superiority. On the other hand, when targets were presented in central vision, with fixation either on the first or the last letter, then little (Ex-

Figure 7. Percentage of correct word identifications as a function of VF and cue validity in Experiment 4.

periment 2) or no (Experiment 4) effects of spatial cuing were found, although we continued to observe a strong effect of VF. In what follows we discuss three main aspects of our results.

Spatial Attention and Stimulus Eccentricity

In line with Battista and Kalloniatis's (2002) results, we found comparable RVF advantages at different retinal eccentricities: Word recognition was better in the RVF than in the LVF independent of target word eccentricity. In support of this, there was no hint of an interaction between eccentricity and VF in the cross-experiment analyses. On the other hand, the attentional benefit induced by valid spatial cues was clearly much larger when target words were presented in peripheral vision than when they appeared in central vision. This was confirmed by a significant interaction between eccentricity and cue validity in the cross-experiment analyses. This reduced effect of spatial cuing with central presentation of target words is at odds with Posner's (1980) conclusion that the perceptual benefit induced by valid cues may be the same for the whole VF. Our results clearly indicate that attentional factors do not have the same influence in central and peripheral vision. Thus, while VF effects appear to operate continuously across the fovea and parafovea (as previously reported by Brysbaert et al., 1996), effects of spatial attention do not. It is therefore unlikely that attentional biases are the common cause of VF and VP effects. The modulation of VF effects by spatial cues (to be discussed in more detail below) lends support to an explanation of such effects in terms of attentional/perceptual biases. The absence of a modulation of VP effects in Experiments 2 and 4 of the present study (and in previous pilot work; see note 5) is evidence against an account of such effects in terms of attentional/perceptual biases.

At an empirical level, our findings help clarify certain discrepancies in prior studies of spatial cuing and word recognition. Auclair and Siéoff (2002), using foveally presented targets, found a spatial-cuing effect for words only in certain conditions (i.e., with increased stimulus length or reduced exposure duration). In contrast, Nicholls and Wood (1998) and Lindell and Nicholls (2003) found robust cuing effects for peripherally presented words. This pattern fits with our observation of small and fragile effects of cuing in conditions similar to those in Auclair and Siéoff's study but robust effects in conditions similar to those tested by Nicholls and colleagues. Also in line with this pattern is the recent finding of Golla, Ignashchenkova, Haarmeier, and Thier (2004), which showed, in a spatial resolution task, that cuing benefits appeared only beyond 3° of eccentricity (and that benefits improved up to 15° of eccentricity). The increase in cuing effects as stimuli became more eccentric might reflect a fundamental difference in the specialization of central and peripheral vision. It is well known that visual acuity, resolution, and contrast sensitivity are higher in central than in peripheral vision. According to Carrasco, Williams, and Yeshurun (2002), covertly allocating attention to a location enhances stimulus discriminability, and the magnitude of this effect increases with eccentricity. The finding that attentional benefits increase as a function

of eccentricity indicates that covert attention helps most where resolution is poorest (Carrasco & Yeshurun, 1998; Yeshurun & Carrasco, 1999).

More generally, the finding that spatial cuing effects vary as a function of eccentricity suggests that reallocation of attention away from a central fixation point is necessary only above a certain level of eccentricity. Before that level of eccentricity is attained, participants can apparently spread attention across a large enough window that they are able to process all targets that fall within that window with equal ease (this would be the case for centrally presented targets in the present study). In this case, despite the fact that spatial attention is drawn by the cue to one side of the word, letter identification may benefit from a deployment of spatial attention from the cue location to the entire spatial extent of the stimulus. Consequently, letter representations on the uncued side can be as activated as letter representations on the cued side, and still no cuing effect would emerge. However, the present study does not allow us to determine whether it is the eccentricity of the entire stimulus that critically determines the pattern of results, or whether it is just the eccentricity of the most eccentric letters (i.e., initial letters in LVF, final letters in RVF). Future research comparing short and long words would help to answer this question.⁷

Spatial Attention and VF Asymmetries

The results of this study do provide some evidence that attentional factors may at least partly underlie VF asymmetries. Consistent with prior visual half-field research (in languages read from left to right), the results of the present experiments indicate a strong RVF advantage for word recognition. More importantly, we found a significant interaction between VF and cue validity in Experiment 1, showing a stronger cuing effect for the LVF than the RVF (in other words, valid cues reduced the RVF advantage). These results are consistent with those obtained by Mondor and Bryden (1992), Nicholls and Wood (1998), and Lindell and Nicholls (2003), who demonstrated that the presence of a valid spatial cue can reduce the size of RVF superiority. However, contrary to Lindell and Nicholls's (2003) and Nicholls and Wood's (1998) findings, in our study, spatial cuing still had a strong influence on identification of words presented in the RVF. This could be due to the increased sensitivity of the perceptual identification paradigm as a tool for observing effects of spatial cues compared with the word-naming task. (Note that perceptual identification also provides a more sensitive measure of VP effects than do lexical decision and naming).

Our preferred explanation for this pattern of effects is that there is a mechanism that biases reflexive attentional orienting as a function of reading direction (Eviatar, 1995). Thus, for our participants, given a central fixation point and a neutral (or no) spatial cue, attention would be initially deployed more to the right than to the left of fixation. Thus, any stimulus appearing to the right of fixation would benefit from this asymmetric deployment of attention compared with stimuli appearing to the left of fixation. Spatial cues act to modify this natural deployment of attention (assumed to be operational in the neutral cue

condition) by biasing attention toward the cue location. Assuming a limit to the total amount of benefit that can be gained from attentional orienting, targets appearing in the RVF benefit less from an RVF cue than do LVF targets from a LVF cue. Whether or not there is a reduced cue benefit for the RVF depends on the size of the RVF advantage in the neutral cue condition. As the RVF advantage diminishes, the interaction effect also tends to disappear. This is what we found in Experiment 3, in which a reduced RVF advantage in the neutral cue condition allowed equivalent cue benefits to emerge for the RVF and the LVF. The reduced RVF advantage in the neutral cue condition in Experiment 3 was probably the result of the type of neutral cue that was used in this experiment. Experiment 1 used two separate masks, each matched in length and position to the two possible target locations, whereas Experiment 3 used a long continuous mask that covered both possible target locations and everything in between. It would appear that the continuous mask of Experiment 3 reduced the operation of attentional biases, hence reducing the RVF advantage in the neutral cue condition. The presence of two distinct masks in the neutral condition of Experiment 1 would encourage reflexive attentional orienting and the associated RVF bias.

Marzouki, Grainger, and Theeuwes (2007) have recently found evidence that similar attentional mechanisms underlie RVF asymmetries and spatial cuing effects. The important aspect of the Marzouki et al. study is that the targets used were always single letters presented on fixation, and the cuing manipulation was performed on subliminally presented prime letters to the right and left of central fixation. Priming effects (i.e., an advantage for primes that were the same letter as the target compared with a different letter) were greater for primes presented in the RVF and for primes occurring in the location cued by an abrupt onset stimulus. Most important, cuing effects were indeed larger for LVF primes. The fact that effects of VF and cue validity were obtained for subliminally presented letters (no participant could discriminate letter primes from pseudoletter primes above chance levels of accuracy) points to a very early influence of attentional mechanisms during the perception of complex stimuli.

Spatial Attention, Word Frequency, and Lexicality

Main effects of word frequency were obtained in all four experiments, and the effects of spatial cuing were approximately the same size for both LF and HF words. There was no hint of an interaction between cue validity and word frequency in any of the experiments. These results replicate those reported by McCann et al. (1992) and Ortells et al. (1998) and do not fit well with prior claims that the effectiveness of spatial cuing depends on stimulus familiarity; that is, the less familiar the letter string (e.g., nonwords, LF words), the more effective the cue will be (Auclair & Siéoff, 2002; Siéoff & Posner, 1988).⁸ According to McCann et al., additive effects of spatial attention and word frequency indicate that the effects of spatial attention are located in a stage separate from the stage that it is sensitive to word frequency. Such a finding is therefore consistent

with the proposal that spatial attention influences early stages of word processing (i.e., prior to the point at which word frequency starts to influence processing). However, it is also consistent with a cascaded activation model in which word frequency determines the connection weights (e.g., between letter and word representations), and spatial attention provides an additional activation boost to stimuli that appear at the cued location. In this type of model, both attention and frequency operate to increase the amount of activation arriving at whole-word representations, thus facilitating word identification.

We did, however, observe an interaction between word frequency and VF in Experiments 2 and 4 (central presentation of target words). Effects of VF (an advantage for fixating the first letter of words compared with fixating the last letter) were larger for LF words. This is consistent with O'Regan and Jacobs's (1992) finding that the cost of not fixating the center of centrally presented target words was greater for LF words than for HF words. Furthermore, the absence of an interaction between word frequency and VF effects in the peripheral presentation conditions of Experiments 1 and 3 is consistent with the results reported by Iacoboni and Zaidel (1996), Koenig, Wetzel, and Caramazza (1992), and Coney (2005). All of these studies reported a clear additivity between VF effects and word frequency in lateralized presentation conditions. This is further evidence that VF effects obtained with central and peripheral presentation of stimuli are at least partly driven by distinct mechanisms. This fits with the main observation of the present study that spatial cuing effects operate differently in central versus peripheral vision. This difference could well be due to the greater importance of lexical constraints with central presentation. HF words would be less sensitive to variations in letter visibility and the consequences of such variations for lexical constraint (Clark & O'Regan, 1999; Stevens & Grainger, 2003).

Furthermore, we also found significantly stronger word frequency effects for centrally presented targets than for peripheral targets (significant eccentricity $\times$ word frequency interaction in the combined analyses). This interaction is consistent with the results obtained by Lee, Legge, and Ortiz (2003), who demonstrated that the time course of frequency effects differed in central and peripheral vision, with frequency effects emerging more slowly in peripheral vision. Significant frequency effects occurred for the shortest exposures in central vision (25–50 msec), whereas significant frequency effects did not occur in peripheral vision until the exposures lasted 100 msec. These results indicate slower lexical processing in peripheral vision. They also show that the lexical system in peripheral vision, when given extra time to make up for slower visual analysis, produced the same pattern of lexical effects.

Finally, the absence of spatial cuing effects for the central presentation conditions of the present study fits with prior reports of reduced attentional influences on the processing of centrally presented word stimuli compared with nonword stimuli (Auclair & Siéoff, 2002; Siéoff & Posner, 1988). This pattern fits the general picture currently emerging from neuropsychological investigations of word and nonword reading. Studies of patients with

hemispatial neglect tested with centrally presented stimuli have shown degraded reports of letters in the contralateral side of nonwords but preserved reports of words (Siéhoff, Pollatsek, & Posner, 1988). A recent study by Facoetti et al. (2006) suggested that part of the nonword reading disability in developmental dyslexia arises from deficient deployment of spatial attention. As suggested by Facoetti et al., these results can be accommodated by a dual-route approach to word reading in which the indirect pathway for sublexical phonological assembly requires attention, whereas the direct lexical-semantic pathway is largely impervious to attentional modulation.

CONCLUSION

The present study adds to the growing literature documenting important differences in the way complex stimuli (printed words in the present experiments) are processed in peripheral and central vision. It is a well-established fact that information available from peripherally presented stimuli is of lower quality, due to the decrease in visual acuity, than information extracted from centrally presented stimuli. The present work suggests that attentional factors can at least partly overcome this initial disadvantage for peripheral vision and that such factors may be partly responsible for differences in recognition accuracy for words presented to the LVF and RVF. On the other hand, although centrally presented words are sensitive to their position relative to fixation (an advantage for fixation on the first letter compared with fixation on the last letter in the present study), our results show that these words are relatively insensitive to attentional factors. This could reflect the distributional properties of spatial attention adapted for the highly specialized task of reading.

AUTHOR NOTE

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NOTES

- Note that Jordan, Patching, and Thomas (2003) have pointed out the fact that investigating hemispheric asymmetries using lateralized stimuli without using an eyetracker to monitor and control fixation location produces substantial amounts of misleading data (see also Jordan, Patching, & Milner, 1998, 2000, and Patching & Jordan, 1998, for similar conclusions). For our purpose, the most important point to emphasize is that the RVF advantage remains even under the stringent testing procedures adopted by Jordan and colleagues.
- This evidence also rules out an account according to which the RVF advantage arises because the beginning of the word is closer to fixation in the RVF than in an LVF presentation, and word beginnings provide more constraining information with respect to word identity than do word endings. This is true only for languages that are read from left to right.
- Note that a clear rightward bias was not obtained in these studies. Only the study by Farid and Grainger (1996) demonstrated a reversal in the asymmetry of the VP curve, using prefixed and suffixed Arabic words (see also Deutsch & Rayner, 1999, for a similar result in Hebrew).
- Recent studies have found that reading causes a redeployment of spatial attention to cover the spatial extent of a letter string (Besner, Stolz, & Boutilier, 1997). For words, despite the fact that spatial attention was drawn by the precue to one side of the letter string, letter identification may have benefitted from a deployment of spatial attention from the cue location to the entire spatial extent of the stimulus. Consequently, letter representations on the uncued side can be activated at a level very similar to the activation level of letter representations on the cued side, and no cuing effect would emerge.
- This pilot work tested the influence of spatial cues on the VP function, which was found to be totally unaffected by the presence of valid (hash marks covering the location of the upcoming target word) versus neutral spatial cues (Ardoint, 2003).
- Note also that a mixed-cues presentation condition was used in the vast majority of experiments on spatial cuing (see Auclair & Siéroff, 2002; Lindell & Nicholls, 2003; McCann et al., 1992; Nicholls & Wood, 1998; Ortells et al., 1998).
- We are grateful to Alexander Pollatsek for this suggestion.
- Note, however, that in our experiments, we cued the position of the entire stimulus. This cuing procedure might be less sensitive to the familiarity manipulation than is the beginning/end cuing procedure used by Auclair and Siéroff (2002), which might be a more effective cue for reorienting attention inside a letter string.