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Deployment of Spatial Attention to Words in Central and Peripheral Vision

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Short title: SPATIAL ATTENTION AND WORD RECOGNITION

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ABSTRACT

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 the last letter of the target word), and words 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 cueing 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.

Key words: Word Recognition; Reading; Peripheral vision; Central vision; Spatial attention;

Reading is a complex process that involves extracting visual information from a currently fixated word, and at the same time 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 this 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 cueing on visual word recognition.

Visual field 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; Mishkin & Forgays, 1952; Ortells, Tudela, Noguera, & Abad, 1998; Nicholls & Wood, 1998; Lindell & Nicholls, 2003). RVF superiority is observed in experimental conditions using brief enough stimulus exposures to prevent eye movements to the stimulus location,¹ hence 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 hemisphere (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 (Brybaert, 1994a; 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 right visual field. 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 (1952). These authors showed that English words were better perceived in the RVF, while Yiddish words were better perceived in the LVF. However other studies have found RVF advantages for languages read leftward, and this has been taken as support for the hemispheric specialization account (Faust, Kravetz & Babkoff, 1993; Malamed & 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 (the perceptual span: approximately four characters to the left of fixation, and 14 characters to the right for a language that is read from left to 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, and Whitney & Lavidor, 2004).

Viewing position 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) moving from fixation on the first letter to fixation on the last letter of the word (Farid & Grainger, 1996; Nazir, O'Regan, & Jacobs, 1991; O'Regan & Jacobs, 1992; O'Regan, Levy-Schoen, Pynte, & Brugallière, 1984; Vitu, O'Regan, & Mittau, 1990). In line with the visual hemifield studies summarized above, the viewing position (VP) function is asymmetric with greater accuracy for fixation in the left part of the word (analogous to RVF presentation, and hence the RVF superiority effect).

Theoretical accounts of the VP effect parallel accounts of VF asymmetries obtained with standard hemi-field 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, 1994b; 2004; Brysbaert & d'Ydewalle, 1988; Brysbaert, Vitu, & Schroyens, 1996) or attentional / perceptual biases (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 will be obtained with eye fixations on the location in the word where the eyes prefer to land (i.e., between the beginning and the middle of the words; Rayner, 1979; Ducrot & Pynte, 2002).

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, while 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 (e.g., English, French) with VP functions obtained in languages read from right-to-left (Arabic, Hebrew). The results at present are not completely favorable to 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; Nazir et al., 2004) than for languages read from left to right (e.g., O'Regan et al., 1984; O'Regan & Jacobs, 1992; Stevens & Grainger, 2003).

That is, this evidence 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 such possible additional mechanism is the way in which 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. (1984) showed that when a word is more highly constrained by its ending, then fixating toward the beginning of words confers less of an advantage compared to words that are highly constrained by their beginning letters (see also Holmes and O'Regan, 1987, for comparable results).³

Most relevant to the present study, is the work of Brysbaert, Vitu, and Schroyens (1996), who demonstrated a strong relation between the VP effect (varying within-word fixation position) and VF effects (with fixation outside of the word). By manipulating in the same study both within-word fixation position and fixation position outside of the word, Brysbaert et al. (1996) observed a continuous VP function that took the shape of a Gaussian distribution with the mode placed left of stimulus centre. Brysbaert et al.'s study would therefore suggest that there is nothing fundamentally different about recognizing a word when fixating its extremities, from 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, 1994b 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 cueing 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 (exogenous cue). With appropriate stimulus presentation conditions (i.e., timing and position of cues and targets), it is typically found that stimuli that appear in the cued location (the valid cue condition) are 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).

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

There is evidence that effects of spatial cueing interact with effects of VF. For example, in Mondor and Bryden's (1992) Experiment 3, the position of a lateralized target was indicated by a peripheral cue (100% valid), and the cue-target stimulus onset (SOA) was varied to manipulate the amount of time available for moving attention. They found that the

RVF advantage for word and nonwords at a 0-ms SOA was reliably attenuated at a 50-ms SOA, thus showing that lexical decision performance can be notably influenced by attentional factors. Using the standard Posner exogenous cueing procedure, Nicholls and Wood (1998) found that cueing effects were only robust 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 (but using lexical decision rather than word naming as in the Nicholls and Wood study), Ortells et al. (1998, Expt 6) reported no interaction between exogenous cueing 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 has (at least numerically) reduced the RVF advantage. Using a beginning/end cueing procedure, Lindell and Nicholls (2003) also obtained a differential cueing effect with 4-letter words presented in the LVF and RVF. RVF presentations were responded to equally efficiently 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 a neutral cue. By contrast, the LVF showed a facilitatory effect of beginning cue, which draws spatial attention to the initial letter cluster. Once again, this finding is in line with Nicholls and Wood's (1998) research, indicating an enhanced effect of valid cues on LVF trials (see also, Gatheron & Siéoff, 1999).

If the RVF advantage is at least partly caused by an attentional bias toward 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, then one only has to assume that combining a RVF cue with a RVF bias generates a smaller gain than that associated with using a LVF cue to counter the RVF bias. Since attention is already principally directed toward the RVF, the effects of a RVF spatial cue could be attenuated by a ceiling effect (i.e., there is a maximum amount of attention that can be directed to a given part of space at a given

time). 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 is counteracted by a RVF bias to cause a small processing cost relative to the neutral cue condition. On the other hand, for LVF stimuli, the invalid cue combines with a RVF bias to cause a much larger cost in processing relative to a neutral cue.

Finally, all the above-cited studies used a peripheral cueing procedure with targets appearing in RVF or LVF. Auclair and Siéroff (2002), however, used a beginning/end cueing 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. They 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 a LVF, but not a RVF cue, while identification of the final three letters was facilitated by a RVF, but not a LVF cue. A cueing effect was also obtained with words in conditions that lowered the level of performance either by increasing length (10-letters word) or by reducing exposure duration (17ms). These results are compatible with an early role of spatial attention in letter string processing, but they also showed that the lexical status of a letter string can directly influence the distribution of attention before identification processes are achieved.⁴

The present study

The above review of the literature has shown that attentional biases may partly underlie effects of visual field and viewing position on visual word recognition. Furthermore, the fact that there is some evidence for an early involvement of attentional mechanisms in

word recognition, and that this 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 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 to the size of VF effects found in other tasks, and therefore 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 examine 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).

Insert Figure 1 about here

Attentional biases offer one common interpretation for both VF asymmetries and within-word VP asymmetries. In both conditions, fixations to the left of the centre of the word are less damaging than fixations to the right of the centre of the word, because attention can be allocated more rapidly and effectively to the right than to the left in people trained to read

in that direction. 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 at least partly due 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 cueing effects on word identification accuracy to words presented to the left and right VF in peripheral vision.

Method

Participants. Forty students from the University of Provence volunteered to participate. Their mean age was 20.1 years. Two of them were left-handed and two were male. All of them 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. Two hundred eight-letter target words were used. Half of the words were low frequency (mean printed frequency less than 3 occurrences per million; New, Pallier, Ferrand & Matos, 2001) and the other half were high frequency (mean printed frequency greater than 33 occurrences per million). In each frequency set, there were 84% nouns, 9% verbs, and 7% 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. 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 following 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. In this case, participants could not guess in advance the type of cue (mixed-cues condition) and the other in which valid and neutral trials were presented in 2 separate blocks. In this case, participants knew in advance what type of cue was presented in each block (blocked-cue condition). In this case, the order of the two blocks was counterbalanced across participants. Therefore Experiment 1 manipulated cue validity (valid vs. neutral), visual field (LVF vs. RVF), word frequency (HF vs. LF), and cue blocking (blocked vs. mixed) in a 2 X 2 X 2 X 2 factorial design. All factors except cue presentation condition were manipulated within participants.

 Insert Figure 1 about here

Apparatus and Procedure. Participants were tested individually. Stimulus presentation was on a 15" color monitor connected to a Pentium III PC computer running the DMDX software package (Forster & Forster, 2001 version 2.9.01). 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, and not to move their eyes. The importance of maintaining eye fixation on this point was repeatedly stressed. 500 ms later, a spatial cue (string of hash marks) appeared laterally for 50 ms. After a 30-ms delay, the word was presented for 80 ms, to the left or to the right of the fixation point. The total elapsed time between the onset of the cue and the offset of the target was therefore 160 ms, 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 not possible, participants were asked to report as many letters as they could. After participants had typed their response and confirmed with <enter>, the screen was cleared and a new trial began following a 500ms delay. A twelve-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 & Discussion

In this and the following experiments an ANOVA was performed on percent correct word identification scores per condition and participant with visual field (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 taken into consideration. The results of Experiment 1 are summarized in Table 1.

 Insert Table 1 about here

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 [$F(1,38) = 49,604, p < .0001$]. Average percentage of word identifications for trials presented to the RVF were 20.62% higher compared to trials presented to the LVF. There was also a main effect of cue validity [$F(1,38) = 219.94, p < .0001$], showing that words were better identified with valid cues than with neutral cues (VC = 71.22%, NC = 38%), and there was no effect of cue blocking [$F < 1$; 53,65% vs. 55,57% for mixed and blocked-cues conditions, respectively].

As can be seen in Figure 2, there was a stronger cueing effect for the LVF [$F(1, 38) = 185.28, p < .0001$] compared to 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 the presence of a valid spatial cue reduced the RVF advantage [$F(1, 38) = 32.81, p < .0001$] compared to the neutral cue condition [$F(1, 38) = 82.56, p < .0001$]. No other interaction approached statistical significance.

 Insert Figure 2 about here

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 cueing procedure. Most important, however, is that spatial cues modulated the VF effect, with valid cues reducing the LVF disadvantage. This result is in line with those 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 to the naming task used by Nicholls and Wood), and the increased sensitivity of our dependent measure now reveals a significant interaction between VF differences and spatial cueing. This

is in line with the hypothesis that at least part of the RVF advantage is due to a preferred attentional allocation to the right of fixation (at least with printed verbal material).

EXPERIMENT 2

Experiment 2 applies the same procedure as Experiment 1 with lower levels of eccentricity and within-word fixations. Words are now presented with either their first letter (RVF presentation) or their last letter (LVF presentation) on the central fixation point. Pilot work in our laboratory has suggested that this change in eccentricity is sufficient to remove all influence of spatial cueing.⁵

Method

Participants. Forty students (4 males) 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 of them were left-handed. All of them were native speakers of French and none had participated in Experiment 1.

Design and Stimuli. The stimuli and design were the same as 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 target words instead of two separate strings of 8 hash marks, as in Experiment 1.

Insert Figure 3 about here

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

 Insert Table 2 about here

Results & Discussion

Percent correct word identification scores 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 visual field [$F(1,38) = 153.20, p < .0001$], reflecting the fact that accuracy of report 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 can be seen in Figure 4, this effect reflected a slightly better performance on valid trials ($M = 71.45\%$) compared to neutral trials ($M = 69.77\%$). Note however that this cueing 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 significant [$F(1, 38) = 1.29, ns$], and this factor did not interact with the other factors [all $F_s < 1$]. There was a significant visual field by word frequency interaction [$F(1, 38) = 6.99, p = .012$], with a stronger word-frequency effect in the LVF ($M = 13.4\%$) compared to the RVF ($M = 9.3\%$). Pairwise comparisons revealed a significant difference between high- and low-frequency words in both visual fields [$F(1, 38) = 116.68, p$

< .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 high-frequency words [$F(1, 38) = 222.88, p < .0001$] compared with low-frequency words [$F(1, 38) = 308.82, p < .0001$].

 Insert Figure 4 about here

As can be seen in Figure 4, the effects of spatial cueing have been drastically reduced in Experiment 2. On the other hand, we still observe the standard RVF superiority in word recognition, and this is about the same amplitude as in Experiment 1 (30% vs. 21% in Experiment 1). Spatial cueing 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 cueing effect was shown for 6-letter and 8-letter pseudowords whereas no cueing effect was observed for words of that length.

However, Experiment 2 differs 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, while in Experiment 2 the neutral cue was formed of a continuous series of pound signs 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 cueing stimulus might be the source of the difference in cueing effects observed in Experiments 1 and 2.

EXPERIMENT 3

Experiment 3 applies the same procedure as Experiment 1 but using a large continuous mask as opposed to two distinct masking patterns in the neutral cue condition.

Method

Participants. Twenty students from the University of Provence volunteered to participate. Their mean age was 24.1 years, one was left-handed, and two were male. All of them were native speakers of French and reported normal or corrected-to-normal vision. None had participated in any of the prior experiments.

Stimuli, Apparatus and Procedure. The stimuli, apparatus and procedure were the same as in Experiment 1 except for the following (see Figure 5): (i) the two distinct strings of hash marks were replaced by a continuous string of 24 hash marks; and (ii) only the mixed-cues presentation condition was used in Experiment 3 since this factor did not significantly affect performance in Experiments 1 and 2 [$F_s < 1$].⁶

 Insert Figure 5 and Table 3 about here

Results & Discussion

The mean percent 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 for 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 58.9% for the RVF, and a main effect of cue validity [$F(1, 19) = 177.42, p < .0001$], showing that words were better identified with valid cues than with neutral cues (VC = 68.25%, NC = 29.45%). There were no significant interactions [all $F_s < 1$].

Insert Figure 6 about here

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

Contrary to Experiment 1, the interaction between cueing and visual field was not significant in Experiment 3. A comparison of Figures 2 and 6 shows that it is the neutral cue condition that has changed across experiments. This was to be expected, given that the only difference between Experiments 1 and 3 is the nature of the neutral cue stimulus (two separate strings of hash marks in Experiment 1, and one long string of hash marks in Experiment 3). The type of neutral cue used in Experiment 3 has 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 operating across clearly distinct spatial locations.

Although stimulus presentation duration had been reduced in Experiment 2 (compared with both Experiments 1 and 3), performance was overall better in that experiment compared to the two others. Thus, it is still possible that the superior performance of participants in Experiment 2 might be the reason for the smaller cueing effects that were observed.

EXPERIMENT 4

Experiment 4 applies the same procedure as Experiment 2 but with a shorter stimulus exposure.

Method

Participants. Twenty students from the University of Provence volunteered to participate. Their mean age was 23.2 years and all reported to have normal or corrected to normal visual acuity. Two of them were left-handed and two were male. All of them were native speakers of French and none had participated in any of the prior experiments.

Design and Stimuli. The stimuli, design and procedure were the same as 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 ms stimulus exposure vs. 50ms in Experiment 2). Furthermore, as in the previous experiment, only the mixed-cues presentation condition was used.

Results & Discussion

The percent 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 visual field [$F(1, 19) = 64.88, p < .0001$]. Mean percent correct word identification was 41.5% for the LVF and 76.65% for the RVF. However, neither the main effect of cue validity nor the interaction between cue validity and visual field were significant [$F_s < 1$].

Insert Table 4 about here

As in Experiment 2, the ANOVA revealed an interaction between visual field and word frequency [$F(1, 19) = 5.03, p = .037$]. As can be seen in Table 2, the difference between high- and low-frequency 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 RVF [$F(1, 19) = 12.08, p = .003$]. Again it appears that with fixations on either the first or last letter of a word, the RVF advantage is reduced in high-frequency words [$F(1, 19) = 143.95, p < .0001$] compared with low-frequency words [$F(1, 19) = 202.80, p < .0001$].

Insert Figure 7 about here

The results of Experiment 4 are clear-cut. In conditions where average performance is in line with that of Experiments 1 and 3, there is absolutely no effect of spatial cueing 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 (Visual field: 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 to 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 re-allocation of attention away from a central fixation point is only necessary above a certain level of eccentricity. Before that level of eccentricity is attained, then it appears that participants can spread attention across a wide enough area in order 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 high- and low-frequency words was more pronounced with 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 x word frequency x visual field interaction did not reach significance [$F(1, 78) = 2.32, p = .13$], there was a significant partial interaction between word frequency and visual field 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, and no interaction for peripheral presentation conditions [$F < 1$]. Thus, word frequency only modulated the effects of visual field in the central presentation conditions of Experiments 2 and 4. There was no interaction between eccentricity and visual field [$F < 1$].

GENERAL DISCUSSION

The present study investigated spatial cueing effects on word identification accuracy to words presented to the left and right visual fields in either central or peripheral vision. The

standard cueing 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 (Experiment 2) or no (Experiment 4) effects of spatial cueing were found, although we continued to observe a strong effect of visual field. 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, independently of target word eccentricity. In support of this there was no hint of an interaction between eccentricity and visual field 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-cueing 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 visual field. Our results clearly indicate that attentional factors do not have the same influence in central and peripheral vision. Thus, while visual field 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 visual field effects and viewing position effects. The modulation of VF effects by spatial cues (to be discussed in more detail below) lend 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 pilot work, footnote 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 cueing and word recognition. Auclair and Siéroff (2002), using foveally presented targets, found a spatial-cueing effect for words only in certain conditions (i.e. by increasing stimulus length or reducing exposure duration). In contrast, Nicholls and Wood (1998) and Lindell and Nicholls (2003) showed robust cueing effects for peripheral presented words. This pattern fits with our observation of small and fragile effects of cueing in conditions similar to Auclair and Siéroff while obtaining robust effects in conditions similar to those tested by Nicholls and colleagues. Also in line with this pattern is the recent finding of Golla et al. (2004) showing in a spatial resolution task that cueing benefits only appeared beyond 3° of eccentricity (and improved up to 15° of eccentricity). The increase in cueing effects as stimuli become 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 vision than in the periphery. 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 the most where resolution is poorest (Carrasco & Yeshurun, 1998; Yeshurun & Carrasco, 1999).

More generally, the finding that spatial cueing effects vary as a function of eccentricity suggests that re-allocation of attention away from a central fixation point is only necessary above a certain level of eccentricity. Before that level of eccentricity is attained, participants can apparently spread attention across a large enough window in order to process with equal ease all targets that fall within that window (this would be the case for centrally

presented targets in the present study). In this case, despite the fact that spatial attention was 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 activated just as much as letter representations on the cued side and no cueing 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 answer this question.⁷

Spatial attention and visual field asymmetries

The results of this study did 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 indicated a strong RVF advantage for word recognition. More importantly, we found a significant interaction between visual field and cue validity in Experiment 1, showing a stronger cueing 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 & 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 (2003) and Nicholls and Wood (1998), spatial cueing 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 compared to the word naming task, as a tool for observing effects of spatial cues (note that perceptual identification also provides a more sensitive measure of viewing position effects compared to those obtained in 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 will benefit from this asymmetric deployment of attention compared to 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 will benefit less from a RVF cue than LVF targets from a LVF cue. Whether or not there is a reduced cue benefit for the RVF will depend on the size of the RVF advantage in the neutral cue condition. As the RVF advantage diminishes, the interaction effect will also tend to disappear. This is what we found in Experiment 3, where 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 as a 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 has 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 (submitted) have recently found evidence that similar attentional mechanisms underlie RVF asymmetries and spatial cueing effects. The important aspect of the Marzouki et al. study is that targets were always single letters

presented on fixation and the cueing manipulation was on subliminally presented prime letters to the right and left of central fixation. Priming effects (an advantage for primes that were the same letter as the target compared to 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, cueing 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 pseudo-letter 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 cueing were approximately the same size for low-frequency and high-frequency 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 Ortell et al. (1998), and do not fit well with prior claims that the effectiveness of spatial cueing depends on stimulus familiarity: the less familiar the letter string (e.g., non-words, LF-words), the more effective the cue will be (Auclair & Siéoff, 2002; Siéoff & Posner, 1988).⁸ According to McCann et al. (1992), 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 where word frequency starts to influence processing). However, it is also consistent with a cascaded activation model in which word frequency determines the connection weights (between letter and word representations, for example), 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, hence 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 visual field (an advantage for fixating the first letter of words compared to the last letter) were larger for low-frequency words. This is consistent with O'Regan and Jacobs (1992) finding that the cost of not fixating the center of centrally presented target words was greater for low-frequency words than high-frequency words. Furthermore, the absence of an interaction between word frequency and visual field effects in the peripheral presentation conditions of Experiments 1 and 3 is consistent with the results reported by Iacoboni and Zaidel (1996), Koenig, Weitzel, and Caramazza (1992) and Coney (2005). All these studies reported a clear additivity between visual field 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 cueing effects operate differently in central and peripheral vision. This difference could well be due to the greater importance of lexical constraints with central presentation. High-frequency 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 with centrally presented targets than for peripheral targets (significant eccentricity x 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 ms), whereas significant frequency effect did not occur in peripheral vision until 100ms. These results indicate slower lexical processing in peripheral vision. They also show that the lexical system in peripheral vision produced the same pattern of lexical effects when given extra time to make up for slower visual analysis.

Finally, the absence of a spatial cueing effect 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 report of letters in the contralateral side of nonwords, but preserved report of words (Siéoff, Pollatsek, & Posner, 1988). A recent study by Facoetti et al. (2006) suggests 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.

CONCLUSIONS

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 due to the decrease in visual acuity, information available from peripherally presented stimuli is of lower quality than the 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 left and right visual fields. 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 to the last letter in the present study), our results show that they are relatively insensitive to attentional factors. This could reflect the distributional properties of spatial attention adapted for the highly specialized task of reading.

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AUTHORS' NOTES

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FOOTNOTES

1. Note that Jordan, Patching, and Thomas (2003) have pointed out the fact that investigating hemispheric asymmetries using lateralised stimuli without using an eye-tracker 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.

2. 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 with LVF presentation, and word beginnings provide more constraining information with respect to word identity than word endings. This is only true for languages that are read from left-to-right.

3. 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).

4. Recent studies have found that reading caused 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 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 activated at a very similar level as letter representations on the cued side and no cueing effect would emerge.

5. This pilot work tested the influence of spatial cues on the viewing position function. The VP function was found to be totally unaffected by the presence of valid (hash marks covering the location as the upcoming target word) versus neutral spatial cues (Ardoint, 2003).

6. Note also that a mixed-cues presentation condition was used in the vast majority of experiments on spatial cueing (see Auclair & Siéroff, 2002; Lindell & Nicholls, 2003; McCann et al., 1992; Nicholls & Wood, 1998; Ortells et al., 1998).

7. We are grateful to Alexander Pollatsek for this suggestion.

8. Note however that in our experiments, we cued the position of the entire stimulus. This cueing procedure might be less sensitive to the familiarity manipulation than the beginning/end cueing procedure used by Auclair and Siéroff (2002), which may be a more effective cue for reorienting attention inside a letter string.

Table 1.

Percentage correct word identification as a function of Cue Validity, Word frequency and Visual Field in Experiment 1. Standard deviations are shown in parentheses.

	Mixed-cues Condition				Blocked-cues Condition			
	LVF		RVF		LVF		RVF	
	HF	LF	HF	LF	HF	LF	HF	LF
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)

Table 2.

Percentage correct word identification as a function of Cue Validity, Word frequency and Visual Field in Experiment 2. Standard deviations are shown in parentheses.

	Mixed-cues Condition				Blocked-cues Condition			
	LVF		RVF		LVF		RVF	
	HF	LF	HF	LF	HF	LF	HF	LF
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)

Table 3.

Percentage correct word identification as a function of Cue Validity, Word frequency and Visual Field in Experiment 3. Standard deviations are shown in parentheses.

	LVF		RVF	
	HF	LF	HF	LF
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)

Table 4.

Percentage correct word identification as a function of Cue Validity, Word frequency and Visual Field in Experiment 4. Standard deviations are shown in parentheses.

	LVF		RVF	
	HF	LF	HF	LF
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)

FIGURES CAPTIONS

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

Figure 2. Percentage correct word identification as a function of visual field and cue validity (valid cue – VC, neutral cue - NC) in Experiment 1.

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

Figure 4. Percentage correct word identification as a function of visual field and cue validity (valid cue – VC, neutral cue - NC) in Experiment 2.

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

Figure 6. Percentage correct word identification as a function of visual field and cue validity (valid cue – VC, neutral cue - NC) in Experiment 3.

Figure 7. Percentage correct word identification as a function of visual field and cue validity (valid cue – VC, neutral cue - NC) in Experiment 4.