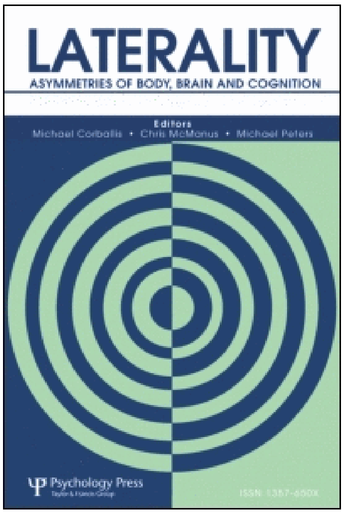

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Lateralised covert attention in word identification

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Lateralised covert attention in word identification

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The right visual field superiority in word recognition has been attributed to an attentional advantage by the left brain hemisphere. We investigated whether such advantage involves lateralised covert attention, in the absence of overt fixations on prime words. In a lexical decision task target words were preceded by an identical or an unrelated prime word. Eye movements were monitored. In Experiment 1 lateralised (to the left or right of fixation) prime words were parafoveally visible but foveally masked, thus allowing for covert attention but preventing overt attention. In Experiment 2 prime words were presented at fixation, thus allowing for both overt and covert attention. Results revealed positive priming in the absence of fixations on the primes when these were presented in the right visual field. The effects of covertly attended primes were nevertheless significantly reduced in comparison with those of overtly attended primes. It is concluded that word identification can be accomplished to a significant extent by lateralised covert attention alone, with right visual field advantage.

Keywords: Parafoveal; Attention; Eye movements; Word priming; Lexical access; Lateralisation.

Research using the divided visual field paradigm has shown a right visual field advantage for a variety of verbal tasks (see Lindell, 2006). It is well documented that words are recognised faster and more accurately when they are presented to the right visual field (RVF) than to the left visual field (LVF). Given the contralateral neuroanatomical organisation of the visual system—with stimuli presented to the right half of the visual field being

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initially projected to the left brain hemisphere—these data have been taken as evidence of a left hemisphere specialisation in early word identification (e.g., Koivisto, 1997; Koivisto & Laine, 2000). Neuroimaging research has provided evidence of this specialisation. Masked words evoke increased cortical responses mostly in left hemispheric foci including left extrastriate areas and the left occipito-temporal pathway (Dehaene et al., 2001, 2004). Similarly, parafoveal word primes presented in the RVF increase neural activation in the left occipito-temporal cortex, whereas for LVF word primes no neural effects have been detected (Pernet, Uusvuori, & Salmelin, 2007).

However, some studies have suggested that the visual field asymmetry in word recognition could be due to an asymmetry in the deployment of visual attention. Mondor and Bryden (1992) found that lexical decision performance was better in the RVF than in the LVF when the location of lateralised verbal stimuli was not precued, thus replicating the typical RVF advantage. In contrast, when a visual signal precued the verbal stimulus, performance improved for LVF stimuli, and the RVF superiority disappeared. This has been interpreted as evidence that the RVF superiority reflects an attentional advantage, with the left hemisphere (LH) requiring fewer attentional resources to recognise words than the right hemisphere (RH). Nicholls and colleagues (Lindell & Nicholls, 2003; Nicholls & Wood, 1998; Nicholls, Wood, & Hayes, 2001), and Ducrot and Grainger (2007) have provided further evidence using a variety of cueing paradigms. Stronger cueing effects were found for the LVF than for the RVF (although the RVF advantage generally remained; Ducrot & Grainger, 2007). The cues were assumed to guide spatial attention to the corresponding location. The fact that word recognition improved for LVF words when they were validly cued (i.e., when the cue signalled the location of the upcoming word) relative to when invalidly cued or non-precued, whereas performance was minimally affected by precueing locations for RVF words, is relevant to the issue of lateralised attention. It suggests that word recognition is minimally or, at least, less dependent on attention in the RVF (and the LH) relative to the LVF (and the RH).

This raises the issue of what kind of attentional resources are involved in the RVF/LH advantage. Attention is a ubiquitous cognitive function that selects and keeps accessible stimulus and mental input for information processing. So far as visual processing is concerned, spatial attention involves selective allocation of cognitive resources to specific locations or stimuli. Two spatial attention mechanisms have been identified: An overt mechanism, which selects and sends the input to the visual cortices by shifting the gaze to a target stimulus, and a covert mechanism, which amplifies target signals through internal neural adjustments without eye movements (Liversedge & Findlay, 2000; Wu & Remington, 2003). Overlapping and common brain areas are activated by both eye movements and covert shifts of attention (Corbetta, 1998; Grosbras, Laird, & Paus, 2005).

Nevertheless, the two mechanisms can be dissociated at neurophysiological and cognitive levels (Hunt & Kingstone, 2003; Posner & Petersen, 1990), with covert shifts generally preceding overt saccades (Awh, Armstrong, & Moore, 2006). Covert attention is believed to boost the pre-processing of information in the visual periphery at the location to which the eyes will subsequently be directed (Findlay & Gilchrist, 2003). Covert attention is generally assumed to shift from one location to another in the visual field faster (50–100 ms) than the eyes (150–200 ms per saccade; see Lachter, Forster, & Ruthruff, 2004; Rayner, 1998). Accordingly, the different time course will lead to relatively different contributions to word identification.

The covert vs overt distinction is relevant to determine whether the RVF/LH superiority in word recognition—due to the hypothesised attentional advantage—involves truly covert mechanisms or also overt mechanisms. The critical issue is whether the asymmetries affect specifically covert attention, i.e., whether covert attention is lateralised towards the RVF, or whether they apply generally also to overt attention. In other words, does covert attention prioritise input coming from the RVF, or does the overt attentional system bias eye movements to the RVF as well? In prior studies, experimental manipulations have been employed to direct the viewers' attention away from the "unattended" words by means of instructions, separate stimulus location, masking, or cueing procedures. However, the extent to which this affected overt vs covert attention is unclear. In fact, Lachter et al. (2004) have critically argued that various forms of attentional "slippage", i.e., uncontrolled allocation of attention to stimuli, may have occurred in studies showing processing of "unattended" words. Voyer (2001) and Bourne (2006) have stressed the importance of controlling for the locus of attention when assessing laterality, particularly where the viewer is fixating. To separate the contributions of overt and covert attention it is important to manipulate whether the viewer can or cannot fixate the lateralised stimulus. In studies employing precueing of lateralised verbal stimuli presented for 150 ms or less, it is unlikely that saccades occurred and that the stimulus was fixated in the invalid-cue condition (e.g., Koivisto & Laine, 2000; Nicholls & Wood, 1998). However, the possibility of overt fixations cannot be ruled out, due to express saccades that can be performed at latencies well below 150 ms (see Delinte, Gomez, Decostre, Crommelink, & Roucoux, 2002).

An adequate approach to deal with fixation control, and thus the separation between the contribution of covert and overt attention, involves the use of eye movement monitoring (see Bourne, 2006). Nicholls and Wood (1998), Nicholls et al. (2001), and Lindell and Nicholls (2003) monitored eye movements by using a video camera and zoom lens, mounted above the computer monitor and focused on participant's eyes. Trials with eye movements to the lateralised words were discarded, yet an RVF advantage was found, thus suggesting the involvement of covert attention alone.

However, the spatial accuracy and the temporal sampling rate of this procedure may not have been optimal. With a sophisticated eyetracker (spatial accuracy: better than 0.5 degrees; sampling rate: 250 Hz), Hyönä and Koivisto (2006) also found an RVF advantage in word detection, even after the trials with eye movements were removed. In a further step, Marzouki and Grainger (2008) used forward and backward masking of the prime, while recording eye movements (also with a 250-Hz eyetracker) and testing for visibility of the prime. After removal of trials with eye movements towards the prime, and when only participants with the lowest level of prime visibility were included, significant repetition priming was found for prime words in the RVF. This is consistent with the hypothesis that the attentional advantage of the RVF/LH involves a covert attention mechanism, in the absence of overt attention.

The current study aims to extend and refine this conclusion with additional methodological controls and measures, and also to explore the specific role of covert attention *relative* to overt attention in the RVF/LH word recognition advantage. In other words, whether there is lateralisation of covert attention in the absence of lateralisation of overt attention. First—in line with the Hyönä and Koivisto (2006) and Marzouki and Grainger (2008) methodology—we used an eyetracker to control for eye movements. In addition, we used a gaze-contingent foveal-masking technique that blocks foveal fixations on the lateralised stimulus, thus preventing overt attention to the stimulus, yet keeping it available parafoveally to covert attention (see below). Similar kinds of masking procedures have been recommended by Bourne (2006). This procedure complements the pre- and post-prime masking used by Marzouki and Grainger (2008). The gaze-contingent masking allows the viewers to move their eyes freely, but ensures that the prime cannot be foveally fixated *during* its presentation (rather than only *before* or *after*, as is the case with the forward and backward masking procedure). Accordingly, there is no need to remove trials with eye movements when gaze-contingent masking is used. Second, to extend Hyönä and Koivisto's findings (2006), we used a *word identification* priming paradigm and measured decision latencies. In contrast, these authors assessed *word detection*, i.e., word vs nonword discrimination, and measured performance accuracy. In the detection paradigm, a single lateralised word or nonword is presented on each trial. In priming paradigms, a lateralised prime word is followed by a target word: Processing of the prime is inferred from facilitation effects on the target when the prime and the target are related, relative to when unrelated. Briefly, whereas the detection paradigm determines whether the viewer has perceived *a* word, the identification paradigm serves to determine *which* word has been perceived.

To assess lateralisation of word identification in the current study, a prime word presented either to the LVF or the RVF was followed by a string of letters as the target at fixation. In a lexical decision task participants responded whether the target was a word or not. The prime and the target word were identical (e.g., *word* and *WORD*) or unrelated (e.g., *card* and *WORD*) in meaning, although different in type of letters (upper vs lower-case).[1] If the lateralised prime is processed, faster lexical decision responses on the target should occur following identical primes than unrelated primes. To determine whether there is any effect of covert attention in the absence of overt attention, in Experiment 1, prime words were presented parafoveally (2.2° away from fixation), briefly (150 ms), and foveally masked. The prime word was masked by Xs if the viewer initiated a saccade towards it, but remained unmasked as long as the viewer kept looking at a central fixation point. Thus, assuming that covert attention shifts can take between 50 and 100 ms (Lachter et al., 2004), our conditions allowed for covert, but not overt, attention to the prime. In Experiment 2 manipulations were used to estimate the relative roles of covert and overt attention: Unmasked prime and target words were presented at fixation, i.e., foveally, for 150 ms. Accordingly, both overt and covert attention could be allocated to the primes. While priming effects in the parafoveal condition (Experiment 1) provide information about the specific contribution of covert attention, the difference between the parafoveal and foveal condition (Experiment 2) serves to estimate the relative roles of overt and covert attention.

EXPERIMENT 1

A parafoveal prime word was presented for 150 ms, 2.2° away from a central fixation point. Following a 150-ms blank interval, a word or non-word appeared as a lexical decision target. The prime—either identical or unrelated to the target—could not be directly looked at due to gaze-contingent foveal masking. Faster target responses in the identical—relative to the unrelated—condition will reveal processing of the prime by covert attention. If this priming effect involves genuine lateralisation of covert

[1] We used a repetition-priming paradigm. Although repetition priming can be affected by processing of the word form (i.e., orthographic and phonological codes), it is also sensitive to word meaning. The finding that repetition priming effects are much stronger for words than for nonwords implies that the priming effect is not occurring merely at the letter level; if priming was determined only by the verbal stimulus form, it should occur similarly for words and nonwords (see Lachter et al., 2004). In addition, Pesciarelli et al. (2007) found that both repetition and semantic priming effects are modulated by at least partially overlapping neural mechanisms. Furthermore, repetition priming is less affected by attentional manipulations than semantic priming (Fabre, Lemaire, & Grainger, 2007). This implies that, if an RVF word recognition advantage appears under covert attention conditions in (the less sensitive) repetition priming, then such lateralised covert attention is expected be involved—even more strongly—also in semantic priming.

attention to the RVF, it will occur in the absence of a corresponding lateralisation of overt attention (i.e., saccades to the RVF prime).

Method

Participants. A total of 24 first-year psychology undergraduates (19 female; 22 right handed) from the University of La Laguna participated for course credit.

Stimuli. We used 144 Spanish words as targets (see Calvo, Castillo, & Fuentes, 2006). These words were also presented as parafoveal primes in the prime–target *identical* condition. An additional 144 words served as parafoveal primes in the prime–target *unrelated* condition (the targets were the same as in the prime–target identical condition). We assessed word lexical frequency and neighbourhood size (the number of other words differing in only one letter) by means of B-Pal (Davis & Perea, 2005), a database and application for computing psycholinguistic statistics. The mean target (and prime) word frequency in the identical condition was 37.00 occurrences per million ($SD = 46.18$); words ranged from five to seven letters long, with 5.96 mean number of letters ($SD = 0.76$); the mean number of orthographic neighbours was 1.53 ($SD = 2.08$). The prime words in the unrelated condition were matched in length with those in the identical condition, and were of virtually the same frequency ($M = 36.90$; $SD = 45.73$) and equivalent orthographic neighbourhood size ($M = 1.83$; $SD = 1.96$). There were also 48 nonword stimuli (with one letter of a valid word changed).

Apparatus and procedure. Stimuli were presented on a 21-inch monitor with a 120-Hz refresh rate, connected to a Pentium IV 3.2-GHz display computer. Participants' eye movements were recorded with an EyeLink II tracker (SR Research Ltd., Mississauga, Ontario, Canada), connected to a Pentium IV 2.8-GHz host computer. The sampling rate of the eyetracker was 500 Hz and the spatial accuracy was better than 0.5°, with a 0.01° resolution in pupil tracking mode.

The prime words subtended a visual angle between 1.3° and 1.8° horizontally, and 0.4° vertically. The probe string subtended a visual angle between 1.4° and 2.0° horizontally, and 0.5° vertically. Participants had their head positioned on a chin and forehead rest to prevent movements, with their eyes located at a constant distance of 60 cm from the centre of the screen. Participants responded to the probe in a lexical decision task by pressing one of two keys (for "word" and "nonword") in a response box.

Figure 1 shows the sequence of events on a trial. A string of xx + xx ($1.4° \times 0.4°$) was presented in the centre of the screen. When the participant fixated the cross of this string, the prime display appeared for 150 ms, with one parafoveal word to the left or right. The distance between the fixation cross and the inner edge of the parafoveal prime was 2.2°. After a blank interval of 150 ms, a probe word (or nonword) appeared at fixation (i.e., replacing the central string of xx + xx) for lexical decision. A 300-ms prime–probe SOA was used because it has been shown to produce positive priming (Ortells, Abad, Noguera, & Lupiáñez, 2001). The probe was displayed until response or for a maximum of 1250 ms. There was a 1500-ms blank intertrial interval. Participants were instructed to keep fixating at the centre of the screen throughout the trials, as the relevant stimulus for lexical decision would always appear on that location. A gaze-contingent-display change was implemented such that the initial and the last x of the xx + xx string constituted a boundary. Whenever the participant made a saccade that crossed either of these boundaries, the parafoveal prime word turned to a row of Xs (that masked the word). Each participant was presented with 30 practice trials and 192 experimental trials (144 involving probe words and 48 involving nonwords), randomly. We used this low nonword ratio to minimise postlexical strategies (see Ortells et al., 2001; see Neely, 1991, for a discussion of this issue).

Design. The experimental design involved two within-participant factors: prime–probe Relatedness (identical vs unrelated) and prime Visual Field (left vs right). For each participant, half of the target words were

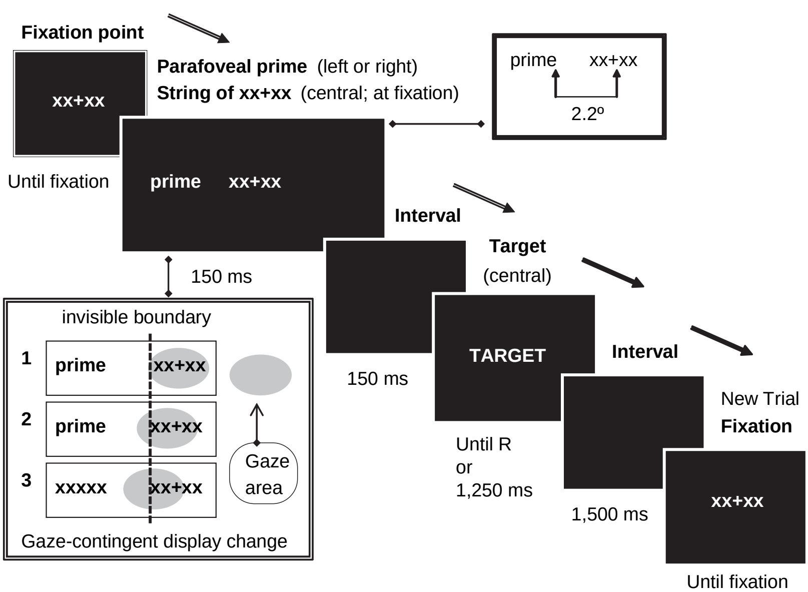

Figure 1. Sequence of events on each trial in Experiment 1.

preceded by an identical parafoveal prime word, and for the other half by an unrelated parafoveal prime word. In the identical condition the same word was presented as a prime and a target. In the unrelated condition the prime and the target word were different. In both conditions the prime was typed in lowercase and the target in uppercase, to minimise visual similarity. Half of the identical primes and half of the unrelated primes appeared in the LVF and the other half appeared in the RVF. On trials involving nonword targets, half of these were preceded by identical nonwords and the other half by words. The nonword trials were not used for data analysis.

Measures. Eye movements were assessed by (a) the probability of initiating a saccade towards the prime, (b) the saccade latencies (i.e., the time taken to initiate an eye movement from the central fixation point towards the prime), and (c) the end time (i.e., the time taken to land a fixation on the prime location) of these saccades. Priming effects were assessed by means of response accuracy and reaction times to the target words in the lexical decision task.

Results

Saccades towards the parafoveal prime. The probability, latency, and end time of saccades were analysed by means of t tests for dependent samples, as function of visual field of prime. The duration of fixations on the prime picture area was also examined when there was any fixation. The probability of initiated saccades was equivalent for the LVF ($M = 0.098$; $SD = 0.15$) and the RVF ($M = 0.096$; $SD = 0.14$), $t < 0.5$. Accordingly, there were eye movements towards the prime words in 9.7% of the trials. Neither the time taken to initiate a saccade from the central fixation point nor the end times of saccades landing on the prime location was significantly different as a function of visual field (ts < 0.5). The mean latency or *start* time of these saccades was 137 ms ($SD = 11.13$) for the LVF and 138 ms ($SD = 9.07$) for the RVF. The mean *end* time of the saccades was 157 ms ($SD = 13.33$) for the LVF and 163 ms ($SD = 14.67$) for the RVF. Of those trials in which there were eye movements (i.e., 9.7%), the percentage of saccade end times shorter than 150 ms was 18.4%. This reveals that in less than 1.5% of the total number of trials (including those with no saccades) were there fixations on the prime location. For the few trials (less than 1.5%) in which saccade end times were less than 150 ms, the mean duration of fixations on the prime area was 15 ms. Even so, whenever this occurred, the gaze-contingent-display change masked the prime word, which therefore could not be foveally fixated.

Lexical decision performance on the probe. Response accuracy in the lexical decision task and latencies of correct responses were analysed with 2 (prime–target relatedness) $\times$ 2 (visual field of prime) ANOVAs. Accuracy was

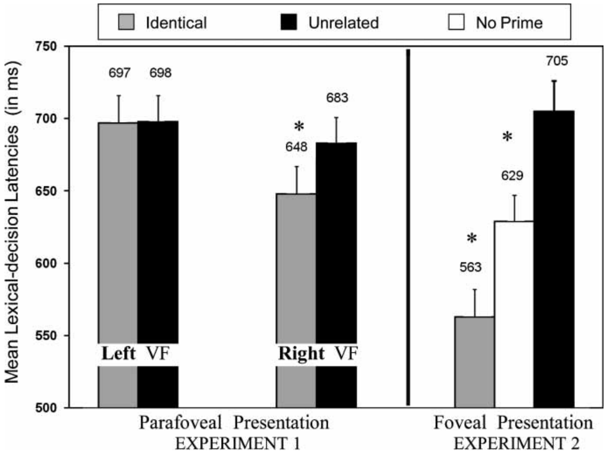

Figure 2. Mean correct response times (in ms) to target words following an identical or an unrelated prime word in Experiment 1 (separately for the left and the right visual fields), and Experiment 2. Asterisks show significant differences between conditions.

equivalent in the identical ($M = 0.970$ probability of correct responses; $SD = 0.055$) and the unrelated ($M = 0.961$; $SD = 0.066$) condition, and when primes were presented in the LVF ($M = 0.962$; $SD = 0.058$) and the RVF ($M = 0.969$; $SD = 0.063$), and there was no significant interaction ($F < 1$). The analysis of correct reaction times yielded main effects of relatedness, $F(1, 23) = 13.99$, $MSE = 608.96$, $p < .001$, with faster responses in the identical ($M = 672$ ms; $SD = 95$) than in the unrelated ($M = 691$ ms; $SD = 85$) condition, and effects of visual field, $F(1, 23) = 21.87$, $MSE = 1{,}105.96$, $p < .0001$, with faster responses in the right prime ($M = 666$ ms; $SD = 86$) than in the left prime ($M = 698$ ms; $SD = 95$) condition. Nevertheless, these effects were qualified by a relatedness by visual field interaction, $F(1, 23) = 14.31$, $MSE = 468.79$, $p < .001$. Planned contrasts revealed a significant 35-ms facilitation effect in the identical relative to the unrelated condition for the RVF, $t(23) = 5.56$, $p < .0001$, but a non-significant 1-ms facilitation effect for the LVF. See mean scores in Figure 2 (results from Experiment 2 are also shown for comparison).

Discussion

There were two main findings in this experiment. First, correct lexical decision responses were faster when the target was identical to the prime word than when the prime was unrelated. An interaction with visual field revealed that this priming effect was significant when the prime appeared to the right of fixation, but not when presented to the left. Second, priming occurred in the absence of eye fixations on the parafoveal prime words.

Taking into account (a) the extremely low number of (b) very short fixations on the prime location, which (c) was foveally masked before fixation, it is reasonable to assume that there was no overt attention to the parafoveal words. Importantly, there was no lateralisation of overt attention, as the probability of initiating saccades towards primes in the LVF and the RVF was equivalent. Actually, rather than an RVF overt lateralisation, if anything there was a (non-significant) opposite trend, with *less* saccades, *slower* response latencies, and *longer* saccade end times for primes in the RVF. Accordingly, any prime word processing resulting in priming effects must have been performed by covert attention. This indicates that covert attention makes a significant contribution—on its own—to word identification, in the absence of overt attention. Nevertheless, this contribution is modulated by the lateralised spatial location of the prime, with covert attention processes being effective for words presented in the RVF.

EXPERIMENT 2

The previous results revealed word identification by covert attention. In Experiment 2 we assessed the influence of overt attention, for which prime words were presented at fixation and unmasked. The difference in priming effects between the parafoveal-and-masked and the foveal-and-unmasked conditions will allow us to estimate the relative contribution of covert attention in comparison with overt attention. In addition to an identical and an unrelated prime-probe condition, probes were not preceded by any prime in a control condition.

Method

Participants. A total of 24 undergraduates (19 female) participated for course credit. All the participants in Experiments 1 and 2 were drawn from the same pool of first-year psychology students and were assigned randomly to each experiment. The sample homogeneity was required to make comparisons between the respective data.

Apparatus, materials, procedure, and design. The same target words as in Experiment 1 were used. No eyetracker was used. On each trial, following and replacing a 500-ms central cross, one word (or a string of five crosses in the no-prime, control condition) was presented at fixation as a prime for 150 ms. After a 150-ms blank interval a target word or a nonword appeared at fixation for lexical decision. The procedure was identical to that in Experiment 1 in all other respects. The design involved prime–probe Relatedness (identical vs unrelated vs no prime) as a within- participants factor.

Results

Response accuracy and mean correct lexical decision times in Experiment 2 were analysed in a one-way repeated measures ANOVA (identical vs unrelated vs no prime). There were significant effects on response accuracy, $F(2,\ 46) = 3.80$, $MSE = 0.003$, $p < .05$, (identical $M = 0.989$ probability of correct responses, $SD = 0.02$; unrelated $M = 0.948$, $SD = 0.08$; no prime $M = 0.975$, $SD = 0.06$). After Bonferroni corrections for multiple comparisons, significant differences emerged between the identical and the unrelated condition ($p < .05$). For lexical decision latencies of correct responses to the target there was also a reliable effect, $F(2,\ 46) = 59.90$, $MSE = 2{,}010.36$, $p < .0001$, with significant differences between all three conditions (all ps < .0001, after Bonferroni corrections). Correct responses were 66 ms faster in the identical than in the no-prime condition, which were 76 ms faster than those in the unrelated condition. See mean scores in Figure 2.

Combination of Experiments 1 and 2. To determine the specific contribution of covert relative to overt attention, reaction time data from both experiments were combined in 3 (prime Location: parafoveal left vs parafoveal right [Experiment 1] vs central [Experiment 2]) × 2 (prime–target Relatedness: identical vs unrelated) ANOVA. Main effects of relatedness, $F(1,\ 69) = 240.37$, $MSE = 532.15$, $p < .0001$, and a borderline effect of location, $F(2,\ 69) = 2.89$, $MSE = 16{,}880.74$, $p = .062$, were qualified by a relatedness by location interaction, $F(2,\ 69) = 119.86$, $MSE = 532.15$, $p < .0001$. To decompose this interaction and examine potential differences in the magnitude of the relatedness effect for the parafoveal and the central prime locations, we first computed priming or activation scores (i.e., RTs in the unrelated condition minus RTs in the identical condition), and then conducted planned comparisons between the parafoveal and the central condition. The contrasts revealed that activation scores in the central condition were greater (i.e., a positive priming effect of 142 ms) than (a) in the RVF parafoveal condition (a significant priming effect of 35 ms, as indicated in Experiment 1), $t(46) = 11.61$, $p < .0001$, and, obviously, (b) in the LVF condition (a non-significant effect of 1 ms), $t(46) = 14.51$, $p < .0001$.

Discussion

When prime words were presented foveally, response accuracy was better and response latencies to targets were shorter following an identical prime than following an unrelated prime. Furthermore, correct responses were slower in the absence of a prime than following an identical prime, and they were faster in the no-prime condition than following an unrelated prime.

These convergent findings show reliable priming effects. The most interesting results involved the comparison between the parafoveal and the foveal conditions. Assuming that both overt and covert attention to the prime are available in the central presentation, and that only covert attention is possible in the parafoveal presentation, the priming scores provide an estimate of the relative contribution of each attentional mechanism to word identification. Thus, if we take the 142-ms priming score as the total (100%) joint effect, this implies that the specific contribution of covert attention was practically null (1 ms; i.e., 0.7%) when primes were presented to the LVF, whereas it was significant when the primes were presented to the RVF (35 ms; i.e., 24.6%); on average (18 ms), the effect was not statistically reliable. Hence the difference could be attributed to overt attention. In sum, in spite of an obviously stronger effect of overt attention, covert attention makes its own significant contribution for prime words appearing in the right visual field.

GENERAL DISCUSSION

A major aim of this study was to distinguish between the roles of covert and overt attentional mechanisms in lateralised word processing, with special interest in the unique effects of covert attention. More specifically, we wanted to determine the involvement of covert attention to account for the RVF/LH advantage in word identification. To address this issue, prime words were presented to the left or the right of fixation, such that they were parafoveally visible but foveally masked. This allowed covert attention but prevented overt attention to the words (alternatively, prime words could be foveally visible, thus allowing both overt and covert attention). Results showed word priming under covert-attention conditions (i.e., facilitation in lexical decisions if the prime and the target were related) when the primes were presented to the RVF. Such selective priming occurred in the absence of fixations on the prime words. Furthermore, there were not more initiated saccades, or shorter saccade latencies, or faster saccade end times, to the RVF than to the LVF prime (if anything, the opposite occurred). Essentially, this reveals lateralised word processing by covert attention in the absence of lateralisation of overt attention.

Contribution of covert and overt attention to word identification

A hotly debated issue in psycholinguistic research has been whether word identification requires attention (see Lachter et al., 2004; Neely & Kahan, 2001). Results from dual-task paradigms are mixed. Some studies have concluded that word processing is automatic (Cleland, Gaskell, Quinlan, & Tamminen, 2006), whereas others have shown that it requires access to central attentional resources (Lien, Ruthruff, Cornett, Goodin, & Allen, 2008). When visuo-spatial attention—rather than central attention—has been considered, discrepancies have also emerged regarding its role in word recognition. Whereas some studies have obtained evidence that recognition can take place when spatial attention is not focused on the target words (e.g., Ortells et al., 2001; Tse & Neely, 2007) others have found no support for such a claim (e.g., Duscherer & Holender, 2002; Lachter et al., 2004). In many of these studies, priming paradigms have been used. A prime word typically appeared briefly at locations separate from fixation and was preceded by a cue at a different location, or the prime was displayed between a pre- and a post-mask (i.e., forward and backward masking; e.g., Marzouki & Grainger, 2008). The authors assumed that no eye movements to the primes would occur in such conditions (which was probably correct, but see Delinte et al., 2002). However, generally, eye movements were not monitored and controlled for in this type research (except in the studies by Hyönä & Koivisto, 2006, and Marzouki & Grainger, 2008; see the Introduction; see also Pernet et al., 2007). We cannot rule out the hypothesis that overt attention was involved in most prior findings showing identification of "unattended" words. As a consequence, the relative roles of overt and covert attention cannot be estimated.

The current study makes a contribution regarding the role of attention in two respects. First, it indicates that overt attention is *not* necessary for word identification. This is consistent with prior research, but adds to it by using controls such as the assessment of overt attention *during* the presentation of the prime, as well as foveal masking of the prime *during* its display (rather than pre- or post-masking, as did Marzouki & Grainger, 2008). To ensure that prime words could be processed in the absence of overt attention, we employed most of the methodological requirements suggested by Bourne (2006). These included a 150-ms prime display, parafoveal presentation of the primes and constant viewing distance. As a further control, we used gaze-contingent masking that prevented eye fixations on the primes. Second, our findings support the notion that word identification can be performed by covert attention alone, although to a much lesser extent than by overt attention. In accordance with the Lachter et al. (2004) criteria, our 150-ms parafoveal prime display permitted covert attention. In conjunction with the concurrent foveal masking procedure, the 150-ms display was thus useful to examine the separate effects of covert and overt attention. It is likely that either form of attention is necessary for word identification, but not both.

Consistently, Yamagata, Yamaguchi, and Kobayashi (2000) found ERP activation for words in unattended spatial locations, although the effect was of reduced magnitude relative to that of attended words. Selective overt inattention attenuates rather than eliminates word processing.

Lateralisation of covert attention in word identification

The conclusion that covert attention is sufficient to identify words that are otherwise unattended overtly is, nevertheless, subject to a constraint. Covert attention mechanisms are effective when words appear in the RVF, but not in the LVF. Many priming studies assessing the role of attention in word identification have not lateralised the location of the unattended stimuli. The prime words were presented in the centre of the visual field (e.g., Daza, Ortells, & Fox, 2002), or vertically displaced above (e.g., Lachter et al., 2004), or above or below fixation (e.g., Duscherer & Holender, 2002), but always aligned to the vertical axis, and therefore lateralisation of attention could not be examined. In contrast, priming studies explicitly using the divided visual field technique have generally found lateralisation in word recognition (e.g., Kanne, 2002; Koivisto & Laine, 2000), and single word (rather than prime–target pairs) detection or naming (e.g., Hyönä & Koivisto, 2006; Nicholls & Wood, 1998), with an RVF advantage. In studies using the divided visual field technique, the prime words (or the single words) were typically presented for less than 150 ms, with the inner edges of the word 1.5° or more to the right or left from fixation; in addition, prior to the word, there was generally a visual cue to a different location. It is unlikely that, in these conditions, the lateralisation effects were due to overt attention. Furthermore, Hyönä and Koivisto (2006), Marzouki and Grainger (2008), and Pernet et al. (2007) found such effects even when trials and participants with eye movements towards the prime (or prime visibility levels above chance; Marzouki & Grainger, 2008) were removed.[2] Accordingly, in conditions assumed to allow covert but not overt attention,

[2] The similarity between the current study and the Hyönä and Koivisto (2006), Marzouki and Grainger (2008), and Pernet et al. (2007) studies deserves some additional comments. Hyönä and Koivisto did not use any prime masking, Pernet et al. used forward masking, and Marzouki and Grainger used forward and backward masking (i.e., immediately before and after the prime). In contrast, we used on-line masking that was contingent on, i.e., *during*, eye movements (and thus did not have to remove any trials with fixations on—or visibility of—the prime). This allowed us to demonstrate priming in the RVF—but not in the LVF—in spite of a tendency of more eye movements to the LVF than to the RVF prime. Interestingly, the different methodological approaches yielded lateralised priming effects in all four studies. This supports the robustness of the asymmetric word processing outside the focus of overt attention.

an RVF was confirmed. Our data corroborate this claim under conditions that ensured lack of overt attention, due to foveal gaze-contingent masking.

The RVF advantage in conditions allowing only covert attention can be interpreted as efficient word processing by the left hemisphere (LH). This is consistent with the notion that the LH is able to recognise words using less attentional resources than the RH (e.g., Mondor & Bryden, 1992; Nicholls et al., 2001). Whereas the LH could rely on covert attention, the RH might be more dependent on overt attention. This greater automaticity in verbal processing by the LH is consistent with findings showing priming effects at short SOAs (from 165 to 250 ms), when the prime was presented in the RVF, whereas, at longer SOAs (500 to 750 ms), priming has been obtained for primes in the LVF (Koivisto, 1977; Koivisto & Laine, 2000). A reason for the lower dependence on spatial attention by the LH has been proposed by Lindell and Nicholls (2003; Lindell, Arend, Ward, Norton, & Wathan, 2007). Presumably, the LH and the RH engage different strategies during early processes involved in stimulus encoding. Whereas the LH treats a word as a perceptual whole, the RH processes the letters comprising a word as a series of individual units. The former strategy would place fewer demands on attentional resources than the latter. Consistently, results indicating priming for nonwords only when presented to the LVF, and priming for words mainly when presented to the RVF, suggest an advantage in perceptual analysis for LVF primes and conceptual analysis for RVF primes (Pernet et al., 2007).

Alternatively, the special LH ability to encode verbal stimuli as single units may be favoured by perceptual factors and rightwards reading habits. The initial letters of words presented in the RVF appear closer to central fixation than those presented in the LVF, when words are typically displayed horizontally in divided visual-field tasks. Given that the beginning of words is more informative than the end (Brysbaert, Vitu, & Schroyens, 1996), this would provide RVF words with an identification advantage. Moreover, in most Western languages reading typically proceeds from left to right. This implies that words presented in the RVF are favoured, as their commencing letters appear close to the right of fixation. In contrast, words presented to the left are at a disadvantage because attention must be shifted away in a direction that conflicts with the natural tendency to move the eyes from left to right. Although there are empirical discrepancies regarding this issue (see reviews in Brysbaert et al., 1996, and Lindell, 2006), Battista and Kalloniatis (2002) have found support for the proposition that the RVF advantage is a consequence of attending to a particular area of visual space as part of the normal reading habit, rather than an innate superiority for word recognition in the RVF. It is nevertheless possible that reading habits and hemispheric dominance are complementary, rather than incompatible: The contribution of brain specialisation mechanisms in the LH could be magnified due to left-to-right reading habits.

Conclusions

This study investigated the role of covert spatial attention in lateralised word recognition. There was an identification advantage for prime words presented in the RVF when the primes were foveally masked but parafoveally available. This suggests that there is lateralisation in covert attention in the absence of overt attention. Furthermore, this asymmetric effect occurred even though there was no tendency in the probability of initiated eye movements or saccade latencies towards the RVF, relative to the LVF, thus showing no lateralisation of overt attention. In the absence of overt attention to prime words, covert attention alone is sufficient to identify them. Nevertheless, priming effects were stronger when the prime words were available to fixation, which indicates that overt attention makes a greater contribution than covert attention to word identification. The distinction between overt and covert attention mechanisms has thus provided useful information about the role of attention in lateralised word processing.

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