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Inhibition of return in subliminal letter priming

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ABSTRACT

The present study combined exogenous spatial cueing with masked repetition priming to study attentional influences on the processing of subliminal stimuli. Participants performed an alphabetic decision task (letter versus pseudo-letter classification) with central targets and briefly presented peripherally located primes that were either cued or not cued by an abrupt onset. A relatively long delay between cue and prime was used to investigate the effect of inhibition of return (IOR) on the processing of subliminal masked primes. Primes presented to the left visual field showed standard effects of Cue Validity and no IOR (significant priming with valid cues only). Primes presented to the right visual field showed no priming from valid cues (an IOR effect), and priming with invalid cues that depended on hand of response to letter targets (right-hand in Experiment 1, left-hand in Experiment 2). The results are interpreted in terms of a differential speed of engagement and disengagement of attention to the right and left visual fields for alphabetic stimuli, coupled with a complex interaction that arises between Prime Relatedness and response-hand.

1. Introduction

Since Forster and Davis (1984) seminal paper, the fast masked repetition priming paradigm has become a prominent methodological tool for uncovering early perceptual processes involved in the identification of complex stimuli such as letters and words (e.g., Jacobs & Grainger, 1991; Peressotti & Grainger, 1999; Seguì & Grainger, 1990). In this paradigm a briefly presented, pattern-masked prime stimulus is followed by a target stimulus that typically requires some behavioral response. A repetition priming effect is obtained when participants are faster and/or more accurate to respond when prime and target are the same stimulus (related condition) compared to when prime and target are different stimuli (unrelated condition). Since these priming effects can be obtained with very brief prime durations (where prime stimuli are not available for conscious report), they are thought to reflect the most automatized of the processes involved in identifying familiar forms – those that are likely to be impervious to top–down control. In several recent studies described below, this priming paradigm has been successfully combined with spatial cueing procedures in order to examine attentional influences on the earliest phases of letter and word perception.

In the 1970s and early 1980s, Posner, Eriksen and colleagues (Eriksen & Hoffman, 1972; Eriksen & Yeh, 1985; Posner, 1980; Posner & Cohen, 1984; Posner, Snyder, & Davidson, 1980) developed a classic cueing paradigm to assess the operation of top–down (endogenous) and bottom–up (exogenous) attention. This technique has the advantage of manipulating spatial attention independently of eye movements. Typically, participants have to detect or discriminate a target in the periphery and respond manually by pressing the appropriate response keys. The target stimulus is preceded by a cue which provides information about the location of the upcoming target. Two modes of spatial attention were postulated (Jonides, 1981; Posner, 1980): endogenous versus exogenous. In a cueing version typically referred to as "endogenous", a symbolic central cue points to the likely target location, whereas in the so-called exogenous version, participant's attention is pulled to one of the locations by an uninformative peripheral cue (often an abrupt increase in luminance). With this latter mode of cueing, the typical finding is that when the cue is valid (i.e., the target appears in the cued location) response times are fast and accuracy is high relative to the condition in which the cue is invalid (the target appears in the un-cued location). It is important to note that in exogenous cueing, the cue has no predictive value since targets appear equally often at cued and un-cued locations. Under these circumstances, any cueing effects are presumably due to bottom–up processing, that is, processing which is assumed to be

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independent of the observer's goal or intention and resulting from automatic capture of attention (Jonides, 1981; LaBerge, 1981; Theeuwes, 1991; Yantis & Egeth, 1999; Yantis & Jonides, 1990).

In order to study the involvement of spatial attention in letter and word perception, some recent studies have combined the masked priming paradigm with an exogenous cueing procedure (see Finkbeiner & Forster, 2008 for review). Using a standard masked repetition priming manipulation with word stimuli, two studies have reported evidence for a modulation of priming effects by spatial cues (Besner, Risko, & Sklair, 2005; Lachter, Forster, & Ruthruff, 2004). In these studies, prime words were vertically displaced relative to a central fixation point at which target words appeared, and repetition priming effects were only robust when attention was directed to the prime's location. Marzouki, Grainger, and Theeuwes (2007) found a similar pattern for single letter stimuli with a horizontal rather than vertical displacement of primes. In this study, centrally presented target letters were preceded by masked letter primes that were either the same letter or a different letter and presented either to the left or to the right of fixation. Prime stimuli always appeared with an irrelevant distracter letter at the opposite location. However, prior to prime presentation, an abrupt onset spatial cue appeared either at the same location as the prime or at the opposite location. Repetition priming was only obtained in the presence of valid spatial cues. Moreover, priming effects were found to be significantly stronger for primes that appeared in the right visual field compared with primes that appeared in the left visual field. Marzouki et al. interpreted the latter finding as reflecting a general bias toward the right visual field for linguistic stimuli in languages that are read from left-to-right, such that engagement of attention is faster for stimuli that appear to the right of fixation.

This study provides an extension of the work of Marzouki et al. (2007). With exogenous cues and letter stimuli, this study introduces a different attentional manipulation – inhibition of return (IOR). IOR is observed in a modification of the standard exogenous cueing procedure whereby a target follows an uninformative peripheral cue after a relatively long cue to target onset asynchrony (around 300 ms). IOR is said to occur when participants are slower to detect targets appearing at the cued location compared to the un-cued location (Posner, Rafal, Choates, & Vaughn, 1985). In order to observe IOR, attention must be shifted to a location in space and subsequently disengaged from that location (see Klein (2000) for a review). What is particularly interesting about IOR is that it occurs only after a reflexive shift of attention towards the critical location and is rarely observed when attention is voluntarily allocated to that location (Posner & Cohen, 1984; Pratt, Kingstone, & Khoe, 1997). Hence, IOR is assumed to be a result of disengagement following an involuntary shift of spatial attention.

This study combined IOR with masked repetition priming to examine the dynamics of engagement and disengagement of spatial attention and their influence on the processing of subliminal stimuli. If the engagement and disengagement of attention following an exogenous cue reflect the operation of the same basic mechanism (boosting or diminishing processing of stimuli that appear at a particular location), then we expect to observe an influence of IOR on subliminal priming. More precisely, if IOR leads to a decrease in processing efficiency of stimuli appearing at the cued location, then we expect a decrease in repetition priming effects when primes appear in this location compared to when primes appear in the non-cued location. In this way IOR can be used as a tool to investigate the speed of disengagement of attention from a particular location. Given prior evidence for visual field differences in the effects of spatial cueing and subliminal priming (Marzouki et al., 2007), it is hypothesized that the speed of engagement and disengagement of attention will vary as a function of the location within the visual field, with faster engagement and disengagement for locations in the right visual field. We therefore expect to observe an interaction between priming effects, visual field, and spatial cueing. This experiment uses exactly the same stimuli and procedure as in Marzouki et al. (2007) with two notable differences: a 762 ms delay is introduced between cue and prime onset, and a central cue is introduced between the peripheral cue and the prime stimulus. This is the standard procedure for producing inhibition of return, but in this study it is induced on subliminal prime stimuli rather than on consciously processed targets.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-eight individuals (24 females, 14 males, mean age = 23 - years), students in psychology, participated in the experiment for course credit. All participants were right-handed and reported having normal or corrected-to-normal vision.

2.1.2. Design and stimuli

Sixteen letters (all consonants) of the Roman alphabet served as targets along with sixteen pseudo-letters designed using Font Creator 4.0 software (see Fig. 1 for an example). Each target letter/pseudo-letter was primed either by the same letter (repetition prime) or a different letter (unrelated prime) defining the two levels of the factor Prime Relatedness. It should be noted that pseudo-letter targets were distortions of real letters such that the related prime for a pseudo-letter target was the real letter from which it was derived (see Fig. 1 for an example of a pseudo-letter). Target stimuli were always centrally located, and prime stimuli could appear in the right or the left visual field, defining the two levels of the factor Prime Position. Prior to prime presentation, a cue stimulus appeared either at the same location as the prime (50% were valid trials) or the opposite location (50% of invalid trials), defining the two levels of the factor Cue Validity. Prime Relatedness was crossed with Prime Position and Cue Validity in a $2 \times 2 \times 2$ factorial design. Each participant was tested in each of the 8 experimental conditions with the 16 letters and 16 pseudo-letters being repeated 8 times during the experiment giving a total of 32 trials per condition per participant.

2.1.3. Procedure

Stimuli were displayed on a computer screen in white on a black background in VGA mode (75 Hz refresh). The background luminance of the screen was approximately 1 cd/m^2 and the luminance of all stimuli was approximately 92 cd/m^2. The procedure is described in Fig. 1a. Each trial began with a central fixation point (an asterisk) for 300 ms. The fixation point was then replaced by a complex geometric form (a cross superimposed upon a filled circle) that constitutes the cue stimulus for 150 ms located either left or right of fixation at a distance of 3.21° of visual angle (for a viewing distance of 80 cm). The cue stimulus was replaced by an empty screen during 200 ms and followed by a brief (100 ms) reappearance of the cue at the central fixation[1] location which was then replaced by a second empty screen during 300 ms. A forward mask consisting of a white square with black crossed stripes which appeared both left and right of fixation at the same eccentricity as the cue for 12 ms. The prime stimulus followed the forward mask and appeared either left or right of fixation accompanied by the letter W in the opposite location. The irrelevant W stimulus is used to maintain a balance in visual

[1] The central cue acts like another exogenous cue by dragging attention back to the central location, thereby disengaging attention from the peripheral location. This will procedurally allow the occurrence of IOR.

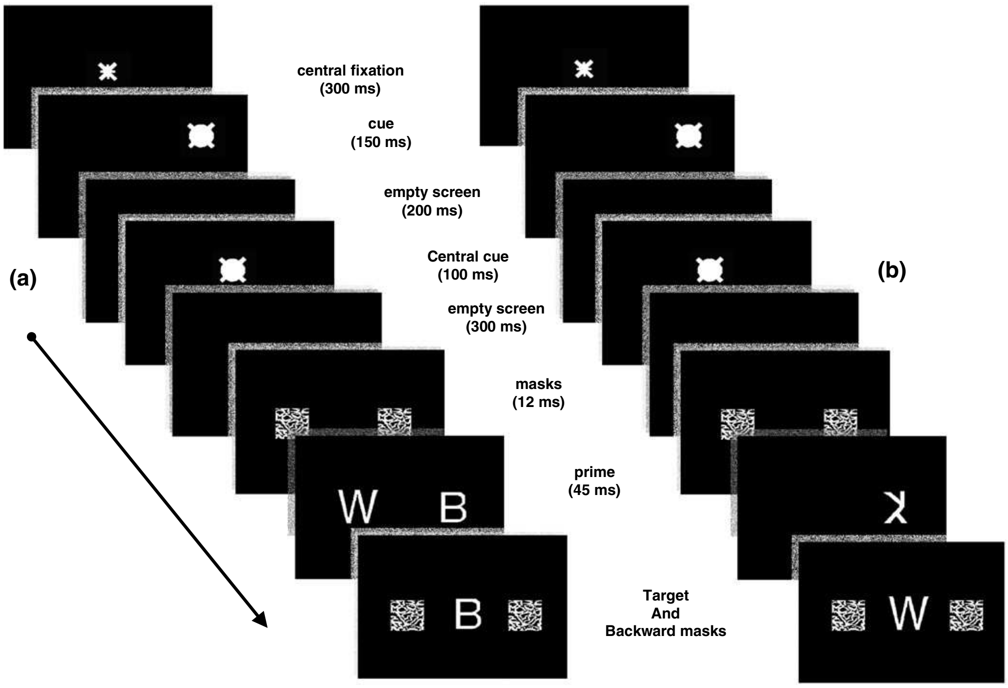

Fig. 1. Structure of a typical trial for the main experiments (a) and visibility task (b). The visibility task shows an example of the pseudo-letter stimuli used in this study.

information across the two visual fields, such that only the initial cue stimulus can attract attention to the left or right. Prime and W presentation lasted 45 ms and was replaced by the centrally located target stimulus and two peripherally located backward masks that remained on the screen until participants responded. The experiment was run in a dimly lit room and was controlled using DMDX software (Forster & Forster, 2003). Participants responded by pressing one of two joystick triggers with their index fingers: right button for letters and left button for pseudo-letters. Participants first performed a practice session with the complete set of 16 target letters and pseudo-letters, followed by the 256 trials of the main experiment in random order. After the main experiment, each participant performed a visibility test using exactly the same stimuli and procedure as the main experiment, except that the target stimulus was always the letter W and primes could be letters (on 50% of trials) or pseudo-letters appearing randomly to the right or the left of fixation and with no filler stimulus (i.e., W) on the opposite side (see Fig. 1b). Participants were informed of the presence of prime stimuli appearing right or left of fixation and had to decide if the prime was a letter or a pseudo-letter on every trial (two-alternative forced-choice instructions).

3. Results

3.1. Main analysis

Table 1 provides the mean correct RTs and percent correct responses to letters and pseudo-letters for each condition in the experiment. The RT data were analysed in an ANOVA with Cue Validity, Prime Position, Prime Relatedness, and Target Type (letter versus pseudo-letters) as main factors. Letter targets were responded to more rapidly than pseudo-letter targets, $F(1,74) = 8.91$, MSE = 18034.09; $p < .005$. None of the other main effects were significant (all Fs < 1). There was a significant interaction between Prime Relatedness and Target Type, $F(1,74) = 11.55$, MSE = 446.13; $p < .005$. None of the three-way interactions were significant (all Fs < 1). Finally, the fourth-order interaction was reliable, $F(1,74) = 6.57$, MSE = 407.21; $p < .05$. This interaction reflects the fact that the triple interaction between Cue Validity, Prime Position, and Prime Relatedness was significant for letter targets, $F(1,74) = 12.60$, MSE = 407.21, $p < .001$, but not for pseudo-letter targets, $F < 1$. The error data showed the same pattern as RTs, indicating an absence of speed-accuracy trade-offs, but there were no main effects or interactions (all Fs < 1).

Giving the peripheral prime presentation (left versus right) and the response-and (right for letter targets versus left for pseudo-letters), a comparison was performed between the compatible stimulus-response condition and the incompatible condition to test a possible occurrence of a Simon effect (Simon, 1969). After averaging across all trials for letters and pseudo-letters, RTs did not differ significantly when the prime position corresponded to the response-hand (RT = 472.1 ms) compared to when the prime position was different from response-hand (RT = 472.7 ms; $t < 1.96$). The same was true concerning cue location – RTs did not differ significantly when the cue position corresponded to the response-

Table 1
Mean reaction times (RT in milliseconds) and accuracy (% error) plus or minus standard errors of the mean for letters and pseudo-letters in Experiment 1

		Left prime				Right prime			
	Cue	Valid		Invalid		Valid		Invalid	
	Prime	Related	Unrelated	Related	Unrelated	Related	Unrelated	Related	Unrelated
Letters	Mean RT	448.7 ± 7.9	469.5 ± 9.4	451.7 ± 8.3	456.8 ± 8.5	454.3 ± 8.8	452.7 ± 8.1	449.9 ± 8.1	465.5 ± 8.7
	% Error	4.0% ± 0.7	5.0% ± 0.8	2.9% ± 0.5	5.0% ± 0.8	5.8% ± 0.9	6.1% ± 1.0	5.8% ± 0.9	5.1% ± 0.8
Pseudo-letters	Mean RT	486.1 ± 8.3	492.5 ± 8.0	491.5 ± 9.8	491.7 ± 9.2	491.1 ± 7.8	488.8 ± 8.6	497 ± 9.4	479.1 ± 7.8
	% Error	5.1% ± 0.8	5.1% ± 0.8	4.7% ± 0.8	5.4% ± 0.9	4.7% ± 0.8	2.7% ± 0.4	5.9% ± 1.0	4.6% ± 0.7

hand (RT = 458 ms) compared to when the cue position was different from the response-hand (RT = 453 ms; $t < 1.96$).

3.1.1. Letter analysis

A repeated measures ANOVA was performed on the data for target letters with Cue Validity, Prime Position and Prime Relatedness as factors. There was a main effect of Prime Relatedness, $F(1,37) = 14.89$, MSE = 510.78, $p < .0005$, and no effects of either Cue Validity or Prime Position, all $Fs < 1$. There was a significant interaction between Cue Validity and Prime Position, $F(1,37) = 4.26$, MSE = 359.91, $p < .05$. No reliable interactions were found between Cue Validity and Prime Relatedness, $F < 1$, nor between Prime Position and Prime relatedness, $F(1,37) = 1.21$, MSE = 560.75, $p > .1$. However, the triple interaction was significant, $F(1,37) = 12.41$, MSE = 413.5, $p < .005$ (see Fig. 2). The triple interaction reflects the fact that the critical two-way interaction between Cue Validity and Prime Relatedness was significant in the left visual field $F(1,37) = 6.48$, MSE = 358.44, $p < .05$, and the right visual field $F(1,37) = 5.49$, MSE = 517.22, $p < .05$, but in opposite directions. Post-hoc analyses (Newman–Keuls test) revealed significant priming effects in the valid cue condition when primes appeared on the left ($p < .05$), and in the invalid prime location when primes appeared on the right ($p < .05$).

In the accuracy data there were no main effects of Cue Validity, Prime Position, or Prime Relatedness, all $Fs < 1$. Also, no second-order interactions were significant (Cue validity × Prime Position; Cue Validity and Prime Relatedness and Prime Position × Prime Relatedness, all $Fs < 1$). Finally, there was no reliable triple interaction between the three experimental factors, $F(1,37) = 1.67$, MSE = 0.33, $p > .1$.

3.1.2. Pseudo-letters analysis

Analyses on RTs showed no main effects of Cue Validity, Prime Position, or Prime Relatedness, all $Fs < 1$. No reliable second-order interactions were found (Cue validity and Prime Position, $F < 1$; Cue validity and Prime Relatedness, $F(1,37) = 1.26$, MSE = 466.12, $p > .1$; Prime Position and Prime Relatedness, $F < 1$). Finally, the three-way interaction was not significant, $F < 1$. There were no significant effects in the repeated measures ANOVA on the accuracy data for pseudo-letter targets (Cue Validity, $F(1,37) = 1.99$, MSE = 0.42, $p > .1$; Prime Position, $F < 1$; and Prime Relatedness, $F < 1$). There were no reliable second-order interactions (Cue validity and Prime Position, $F(1,37) = 1.55$, MSE = 0.42, $p > .1$; Cue validity and Prime Relatedness; Prime Position and Prime Relatedness, and no significant triple interaction, all $Fs < 1$.

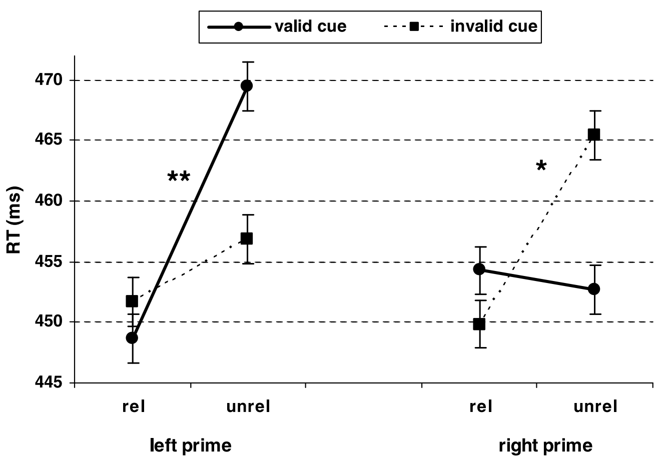

Fig. 2. Three-way interaction between Cue Validity, Prime Position, and Prime Relatedness for all participants in Experiment 1. Significant priming effects are indicated by asterisks (* $p < .05$; ** $p < .01$).

Table 2
ROC curve parameters

Participants	Sensitivity	Specificity	Criterion	A.U.C	95% C.I[a]
S1	100	15.8	>457	0.536	[0.407; 0.661][b]
S2	54.2	79.2	⩽710	0.634	[0.529; 0.730]
S3	91.5	25.0	>415	0.497	[0.368; 0.626][b]
S4	60.3	54.2	⩽873	0.534	[0.427; 0.638][b]
S5	70.0	47.6	⩽1061	0.479	[0.421; 0.684][b]
S6	28.6	84.8	⩽760	0.547	[0.438; 0.653][b]
S7	54.2	100.0	⩽656	0.749	[0.623; 0.849]
S8	65.8	79.2	⩽710	0.740	[0.641; 0.824]
S9	88.4	47.4	⩽1212	0.666	[0.535; 0.781]
S10	55.4	65.4	⩽889	0.582	[0.474; 0.684][b]
S11	64.7	56.7	>617	0.563	[0.433; 0.686][b]
S12	80.9	37.9	>501	0.511	[0.408; 0.614][b]
S13	86.8	63.6	⩽860	0.733	[0.608; 0.836]
S14	48.5	82.8	⩽716	0.676	[0.573; 0.767]
S15	80.5	54.5	⩽818	0.664	[0.533; 0.778]
S16	75.4	36.1	>397	0.525	[0.421; 0.627][b]
S17	42.9	44.0	⩽434	0.604	[0.469; 0.728][b]
S18	52.5	64.7	>726	0.564	[0.458; 0.665][b]
S19	66.6	66.7	⩽836	0.587	[0.451; 0.714][b]
S20	84.7	50.0	>344	0.624	[0.519; 0.722]
S21	92.6	30.6	>260	0.506	[0.377; 0.634][b]
S22	27.6	84.6	>1056	0.527	[0.423; 0.629][b]
S23	58.1	57.6	>485	0.542	[0.413; 0.667][b]
S24	47.2	80.0	⩽582	0.591	[0.486; 0.689][b]
S25	91.9	40.7	>654	0.588	[0.458; 0.689][b]
S26	94.2	21.4	⩽1484	0.527	[0.423; 0.629][b]
S27	71.1	65.2	>516	0.591	[0.458; 0.709][b]
S28	35.8	89.7	⩽706	0.590	[0.485; 0.689][b]
S29	72.4	53.6	⩽649	0.605	[0.467; 0.732][b]
S30	95.1	16.7	⩽1531	0.490	[0.384; 0.597][b]
S31	68.4	65.4	>375	0.654	[0.525; 0.769]
S32	59.1	56.7	⩽1001	0.540	[0.435; 0.642][b]
S33	54.1	65.4	>886	0.536	[0.406; 0.662][b]
S34	68.7	70.8	⩽942	0.720	[0.616; 0.809]
S35	81.4	52.6	>612	0.615	[0.483; 0.736][b]
S36	59.4	67.9	⩽710	0.606	[0.501; 0.704]
S37	30.8	82.6	>1201	0.491	[0.361; 0.621][b]
S38	56.9	59.5	⩽942	0.501	[0.396; 0.605][b]

[a] The 95% Confidence Interval for the area can be used to test the hypothesis that the theoretical area is 0.5. If the confidence interval does not include the 0.5 value, then this is evidence that discrimination performance is significantly greater than chance.
[b] Selected participants at chance level performance.

3.2. Visibility test

Each participant's response was analysed using the standard signal-detection ROC (Receiver Operating Characteristic) procedure (e.g., Swets, 1996). For each participant we calculated a confidence interval of the Area Under Curve (AUC).[2] Twenty-seven participants were at chance level performance (see Table 2). An analysis of the RT results for the subgroup of participants at chance level performance showed exactly the same pattern as the whole group (see Fig. 3).

The percentage correct prime classification (letter versus pseudo-letter) obtained in the visibility test was analysed in a 2 (Cue

[2] Area under the ROC Curve, with standard error (Zhou, Obuchowski, & McClish, 2002). When the variable under study cannot distinguish between the two groups, i.e. where there is no difference between the two distributions, the area will be equal to 0.5 (the ROC curve will coincide with the diagonal). When there is a perfect separation of the values of the two groups, i.e. the distributions do not overlap, the area under the ROC curve equals 1 (the ROC curve will reach the upper left corner of the plot).

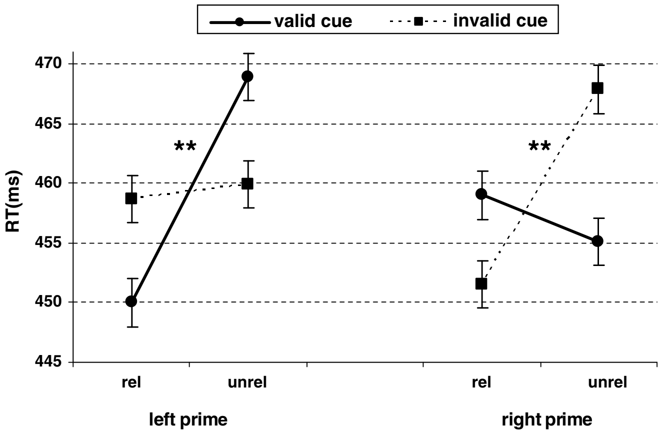

Fig. 3. Three-way interaction between Cue Validity × Prime Position × Prime Relatedness with participants at chance level of performance in the visibility task in Experiment 1. Significant priming effects are indicated by asterisks ($^{**}p < .01$).

Table 3
Mean accuracy (% correct, 2AFC) plus or minus standard errors of the mean for letters and pseudo-letters in the visibility test with all participants in Experiment 1

	Left prime		Right prime	
	Valid cue[a]	Invalid cue	Valid cue	Invalid cue
Letters	65.1% ± 4.3	57.9% ± 4.3	60.9% ± 3.9	63.8% ± 3.6
Pseudo-letters	68.0% ± 3.6	73.0% ± 3.6	61.2% ± 3.4	64.5% ± 3.7

[a] To compare performance on valid **versus** invalid trials in the visibility test χ^2-tests were performed. Results showed absence of significant differences between: valid **versus** invalid cue for the left letter primes, $\chi^2(1, N = 38) = 0.167$; $p > .1$; and left pseudo-letter primes, $\chi^2(1, N = 38) = 0.05$; $p > .1$ and between: valid **versus** invalid cue for right letter primes, $\chi^2(1, N = 38) = 0.01$; $p > .1$; and right pseudo-letter primes, $\chi^2(1, N = 38) = 0.01$; $p > .1$.

Validity) × 2 (Prime Position) ANOVA (see Table 3). The overall analysis with all participants shows no significant main effects of these two factors, $F < 1$, and the interaction was also not reliable, $F(1, 37) = 2.50$, MSE = 149.82, $p > .1$. The same analysis was conducted with participants that showed above chance level performance in the visibility test. The repeated measures ANOVA showed similar results with no reliable main effects, all Fs < 1, and no significant interaction, $F(1, 37) = 1.79$, MSE = 24.86, $p > .1$.

4. Discussion

The results of Experiment 1 are clear-cut. When primes appeared in the right visual field, significant priming was found only in the invalid cue condition, thus suggesting that IOR was operating on subliminal prime stimuli presented to the right. Thus, the valid spatial cue inhibits processing of the upcoming prime stimulus in the RVF hence cancelling priming effects. An invalid cue, on the other hand, does not affect processing of the upcoming prime stimulus and priming effects remain intact. However, the opposite pattern was found for primes presented in the left visual field, with significant priming arising only in the presence of a valid spatial cue (Fig. 2). These results can be accommodated by assuming faster allocation of attention to the right compared with the left visual field, such that attention has sufficient time to engage and disengage before the prime stimulus appears, but only for cues appearing to the right. For cues in the LVF, attention is still engaged at the prime location when processing primes in the valid cue condition, hence the emergence of priming effects.

However, there is one aspect of the results of Experiment 1 that merits further investigation. Even if there was no sign of an effect of compatibility between cue position and response-hand (i.e., a Simon effect) in the overall analysis with letter and pseudo-letter targets, significant priming only arose with letter targets when the spatial cue conflicted with response-hand (i.e., cues appearing to the left – that is invalid cue for primes in the RVF, and valid cues for primes in the LVF). It is therefore possible that cues on the left slowed down overall responses to letter targets, thus allowing priming effects to emerge. Experiment 2 rules out this explanation by having participants respond to letter targets with their left-hand. If the pattern of results found in Experiment 1 is due to a general slowing down of RTs when cues are incompatible with response-hand, then we should see priming effects for valid cues in the RVF and invalid cues in the LVF in Experiment 2. Furthermore, the addition of Experiment 2 will enable a critical cross-experiment analysis in which response-hand is counterbalanced across target type.

5. Experiment 2

5.1. Method

5.1.1. Participants

Thirty individuals (21 females, 9 males, mean age = 22 years), all students in psychology, were paid to participate in this experiment. All participants were right-handed and reported having normal or corrected-to-normal vision.

5.1.2. Design and stimuli

These were the same as in Experiment 1

5.1.3. Procedure

The procedure was the same as for Experiment 1 except for the manual response where participants had to press the left button for letters and the right button for pseudo-letters.

6. Results

Table 4 provides the mean correct RTs and percent correct responses to letters and pseudo-letters for each condition in Experiment 2. The RT data were analysed in an ANOVA with Cue Validity, Prime Position, Prime Relatedness, and Target Type (letter versus

Table 4
Mean reaction times (RT in milliseconds) and accuracy (% error) plus or minus standard errors of the mean for letters and pseudo-letters in Experiment 2

		Left prime				Right prime			
	Cue	Valid		Invalid		Valid		Invalid	
	Prime	Related	Unrelated	Related	Unrelated	Related	Unrelated	Related	Unrelated
Letters	Mean RT	439.7 ± 10.2	450.5 ± 12.0	440.5 ± 9.3	442.6 ± 10.8	445.3 ± 9.9	443.1 ± 10.8	446.9 ± 10.2	437.0 ± 9.0
	% Error	1.9% ± 0.3	3.2% ± 0.5	4.2% ± 0.7	2.7% ± 0.4	3.4% ± 0.5	5.8% ± 0.9	3.7% ± 0.6	3.4% ± 0.5
Pseudo-letters	Mean RT	456.7 ± 10.8	461.1 ± 10.1	458.5 ± 9.4	455.6 ± 10.4	470.3 ± 9.4	466.7 ± 9.3	461.3 ± 11.3	457.9 ± 11.9
	% Error	3.7% ± 0.6	3.8% ± 0.6	4.2% ± 0.7	3.2% ± 0.5	3.6% ± 0.6	5.1% ± 0.8	4.7% ± 0.8	4.6% ± 0.8

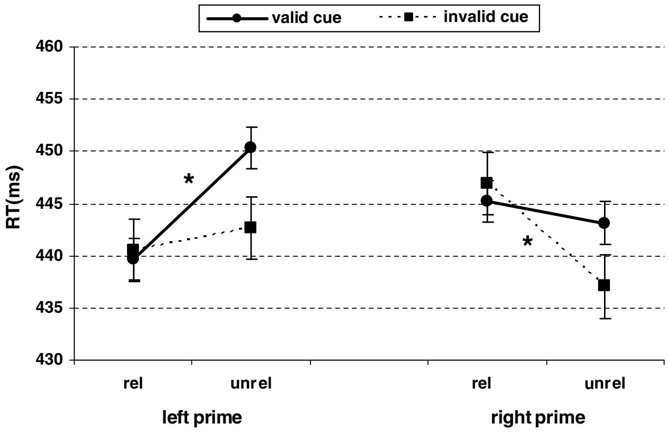

Fig. 4. Effects of Prime Relatedness for letter targets in Experiment 2 as a function of Prime Position and Cue Validity. Significant priming effects are indicated by asterisks (*$p < .05$).

pseudo-letters) as main factors. Letter targets were not responded to more rapidly than pseudo-letter targets, $F(1,58) = 1.75$, MSE = 21757.39; $p > .1$. There was a marginally significant effect of Cue Validity, $F(1,58) = 3.35$, MSE = 608.28; $p = .07$, and a marginally significant interaction between Prime Position and Prime Relatedness, $F(1,58) = 3.48$, MSE = 600.40; $p = .07$. None of the other main effects or interactions were significant (all Fs < 1). The error data showed the same pattern as RTs, indicating an absence of speed-accuracy trade-offs, but there were no main effects or interactions (all Fs < 1).

6.1. Letter analysis

A repeated measures ANOVA was performed on the RT data with the following factorial design: 2 (Cue Validity) × 2 (Prime Position) × 2 (Prime Relatedness). None of the main effects were significant (all Fs < 1). The only interaction to approach significance was between Prime Position and Prime Relatedness, $F(1,29) = 2.83$, MSE = 812.28; $p > .1$. As can be seen in Fig. 4, this is due to the positive priming effect that is present in the left visual field, and a reversed priming effect in the right visual field. Although neither of these effects were significant, post-hoc analyses revealed a reliable priming effect ($p < .05$) when primes were presented in the left visual field in the presence of a valid cue, and there was a significant reversed priming effect for primes in the right visual field in the presence of an invalid cue ($p < .05$). There were no main effects or interactions in the ANOVA performed on the accuracy data.

6.2. Pseudo-letter analysis

An analysis of the RTs to pseudo-letter targets revealed a significant effect of Prime Position, $F(1,29) = 4.49$, MSE = 493.08; $p < .05$ and a marginally significant effect of Cue Validity, $F(1,29) = 3.96$, MSE = 435.71; $p > .05$. There were no significant effects in an analysis of the accuracy data for pseudo-letter targets.

6.3. Cross-experiment analysis

In this analysis the variable Experiment (Experiment 1 versus Experiment 2) was introduced as a between participant factor reflecting the use of the right-hand for letter responses in Experiment 1 and the left-hand for letter responses in Experiment 2. A mixed ANOVA on the RT data revealed a main effect of Prime Relatedness, $F(1,66) = 7.45$, MSE = 470.61; $p < .01$. Other main effects were not significant (Cue Validity and Prime Position, Fs < 1, Experiment, $F(1,66) = 1.14$, MSE = 19746.61; $p > .1$)[3]. The ANOVA revealed significant two-way interactions between Experiment and Prime Relatedness, $F(1,66) = 6.82$, MSE = 470.61; $p < .05$ and between Prime Position and Prime Relatedness, $F(1,66) = 4.20$, MSE = 364.27; $p < .05$. The triple interaction between Cue Validity, Prime Position and Prime Relatedness was also significant, $F(1,66) = 6.51$, MSE = 364.69; $p < .05$, and there was a reliable four-way interaction, $F(1,66) = 5.91$, MSE = 364.69; $p < .05$, that is shown in Fig. 5. The quadruple interaction reflects the fact that there is a significant triple interaction between Cue Validity, Prime Relatedness, and Experiment when primes are presented in the right visual field, $F(1,66) = 4.83$, MSE = 539.01; $p < .05$, and no such interaction for primes in the left visual field.

7. Discussion

The results of Experiment 2 revealed that response-hand has a significant influence on the pattern of priming effects. This is most clearly seen in the significant fourth-order interaction of the combined analysis shown in Fig. 5. Here we can see that the priming effects were quite similar across experiments in all conditions except for primes presented to the right with an invalid cue. This condition generated significant positive priming in Experiment 1 and a significant reversed priming effect in Experiment 2. We have already accounted for the priming effect found in Experiment 1 in this condition, so we now need an explanation for the surprising reversed priming effect found in Experiment 2. We hypothesize that detecting a related prime (not necessarily consciously) presented to the RVF interferes with responses given by the non-dominant left-hand, but only following an invalid cue. Detecting that there is a prime stimulus that is the same as the target stimulus at a given location would arise most often for primes in the RVF following an invalid cue (i.e., no IOR at the prime location). This attracts attention to the side contralateral to the response-hand and interferes with the execution of a manual response. The opposite is not true for detecting a related prime in the LVF and right-hand responses (Experiment 1) due to a general response bias to the right.

Given the relatively ad-hoc nature of our explanation of the reversed priming effect found for primes presented to the right following an invalid cue, we sought additional evidence in favor of this account in our data. According to this account, we ought to find the same reversed priming effect in exactly the same conditions with pseudo-letter targets in Experiment 1. A glance at Table 1 shows that this is indeed the case – there is an 18 ms reversed priming effect for pseudo-letter targets with primes to the right following an invalid cue.

Finally, it is important to note that the results of Experiment 2 allow us to reject an alternative interpretation of the results of Experiment 1 in terms of priming effects for letter targets emerging under the overall slowing down of responses when spatial cues are incompatible with response-hand. This account predicted that priming effects should be found in Experiment 2 for primes presented to the left with an invalid cue, and primes presented to the right with a valid cue. These are the two conditions that showed absolutely no priming in Experiment 2.

[3] Reaction times were numerically faster in Experiment 2 compared with Experiment 1 (452 ms versus 473 ms), and this could be due to the different testing rooms and computers that were used. What is important, however, is that when responses to letter targets were given by the non-dominant hand in Experiment 2, the difference in mean RT to letters and pseudo-letters was numerically smaller (442 ms versus 462 ms) compared with Experiment 1 (457 ms versus 490 ms).

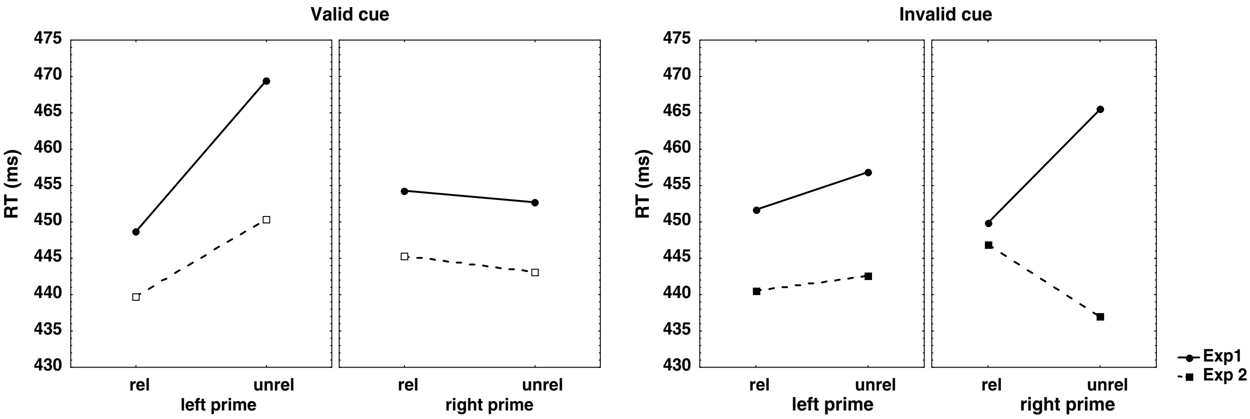

Fig. 5. Four-way interaction between Cue Validity, Prime Position, Prime Relatedness, and Experiment (right-hand response to letter targets in Experiment 1, left-hand response to letter targets in Experiment 2) in the combined analysis.

8. General discussion

This experiment used isolated letter stimuli in a masked repetition priming paradigm with subliminally presented peripherally located primes and an exogenous spatial cueing manipulation. Prior research has shown an influence of exogenous spatial attention on masked repetition priming with word (Besner et al., 2005; Lachter et al., 2004) and isolated letter stimuli (Marzouki et al., 2007). Most relevant for this study, Marzouki et al. found significant repetition priming only when primes appeared at the cued location. Furthermore, Marzouki et al. only found significant priming effects when primes appeared in the right visual field (RVF), and although the triple interaction between cue validity, visual field, and priming was not significant, the strongest priming effects were clearly observed for primes presented in the RVF following a valid cue.

In this study we used the same stimuli and procedure as the Marzouki et al. study except that a delay was introduced between offset of the spatial cue and onset of the prime stimulus in order to generate an IOR effect. This manipulation allowed us to further investigate engagement and disengagement mechanisms that are associated with attentional capture, and how such mechanisms influence the processing of masked prime stimuli. In Experiment 1, the expected IOR effect was obtained for primes presented in the RVF, in that repetition priming was significantly stronger following an invalid cue compared with a valid cue. The opposite pattern of effects was found for primes presented in the LVF, with significant priming only arising in the presence of a valid spatial cue. This pattern can be accommodated by assuming slower engagement and disengagement of attention to the left than to the right, as already suggested by the results of Marzouki et al. (2007). In this case, attention would still be engaged at the prime location during the processing of primes presented to the LVF following a valid cue.

Experiment 2 was designed to rule out an interpretation of the results of Experiment 1 in terms of an interaction between priming and effects of cue-position/response-hand compatibility (a Simon effect) by inverting the response-hand for letter and pseudo-letter targets. The results of this experiment replicated the presence of IOR for validly cued primes presented in the RVF and a standard priming effect for validly cued primes presented in the LVF. Invalid cues continued to cancel priming effects for primes in the LVF, and now generated a reversed priming effect for primes in the RVF. This unexpected reversal of priming effects, compared with the significant positive priming found in Experiment 1 in this condition (see Fig. 5), would appear to reflect a complex interaction between response-hand, priming, and prime and cue location. Our tentative interpretation is that responses generated by the non-dominant left-hand are perturbed by the detection of a related prime in the right visual field. This only happens following an invalid cue, due to the effects of IOR on primes appearing to the right following a valid spatial cue. We found support for this interpretation in the pattern of priming effects to pseudo-letter targets in Experiment 1 (left-hand response to pseudo-letters). There was exactly the same reversed priming effect with primes to the right following an invalid cue, and only in this condition.

The occurrence of IOR in a subliminal masked repetition paradigm demonstrates that the mechanisms involved in generating IOR can influence the processing of stimuli that are not consciously perceived. These results and the results of Marzouki et al. (2007) suggest that the engagement of attention following an exogenous cue and its subsequent disengagement following a new exogenous cue can modulate the amount of processing of subliminal prime stimuli. Following engagement of attention at the prime location, prime stimuli benefit from enhanced processing, and the differential influence of related and unrelated primes accrues. Following disengagement of attention from the prime location, prime stimuli suffer from diminished processing and the differential influence of related and unrelated primes decreases. Our results therefore fit well with the proposal (e.g., Handy, Jha, & Mangun, 1999) that IOR modulates processing at a perceptual rather than at a motoric level.

Visual field (LVF versus RVF) strongly influenced whether IOR was observed in this study. Contrary to the IOR effect found for primes presented in the RVF, primes that were presented in the LVF showed a standard cueing benefit with stronger priming effects for primes appearing at the cued location. Thus, in line with the results of Marzouki et al. (2007), this study also clearly highlights strong visual field differences in the way exogenous attention influences the processing of linguistic stimuli. The strongest priming effects in the Marzouki et al. study were found in the right visual field following a valid cue. This led Marzouki et al. to suggest that speed of allocation of attention following an exogenous cue could be faster to the right than to the left of fixation, given that the stimuli were linguistic in nature and the participants all native speakers of French, a language that is read from left-to-right. As already discussed above, this assumption allows us to interpret the visual field differences found in this study. The presence of a robust effect of IOR requires that attention is already engaged at the prime location when the second disengaging cue appears. This will be the case for cues appearing in the RVF, hence the observed influence of IOR for RVF primes in this study. However, this might not be the case for cues appearing in the LVF, given the greater time required for attention to be allocated to leftward locations. In this case, the process of attentional engagement to a leftward location might then survive the presence of a central disengaging cue resulting in stronger priming effects when primes appear at the cued location in the LVF. [4]

These results that show IOR only for RVF primes have important implications for our thinking with respect to attentional engagement and disengagement processes. It seems that IOR only occurs when attention is first engaged and later disengaged from the prime location. As noted, on the basis of our previous study (Marzouki et al., 2007), the engagement of attention to the RVF is probably due to the habit of reading from left to right. As also noted, it is generally assumed that IOR at a particular location in space follows only after attention has shifted *reflexively* to that location. Typically, IOR does not follow a shift of attention that is directed voluntarily (Posner & Cohen, 1984; Pratt et al., 1997). This latter finding, that the occurrence of IOR is at least to some extent dependent on reading habits suggests that the radical view that IOR is purely exogenous in nature needs revision (see also Gibson & Amelio, 2000).

We assume that the asymmetrical IOR effect is specific to the processing of linguistic stimuli (i.e., letters and words) and results from a bias generated by reading habits in the processing of written language. In other words, our participants (who read from left-to-right) appear to be biased to favor new information appearing to the right of fixation, given that this is where the new information is typically located during reading. This is in line with the standard RVF advantage found for visual word recognition, and the fact that this advantage can be modified by spatial cueing (Kinsbourne, 1970; McCann, Folk, & Johnston, 1992; Mondor & Bryden, 1992; Nicholls & Wood, 1998; Ortells, Tudela, Noguera, & Abad, 1998). Visual field biases and attentional asymmetries have also been found in other tasks, such as when participants judge the orientation of letter stimuli (Robertson, 1995). Ducrot and Grainger (2007) suggested that differences in spatial cueing effects as a function of visual field might be the result of a general endogenous bias towards the right. Under this argument, it is not differences in speed of deployment of spatial attention that are the basis of the asymmetries found in this study, but rather the combination of an endogenous bias to the right with the effects of exogenous cues. The rightward endogenous bias would facilitate attentional deployment to the right following a valid exogenous cue and would interfere with attentional deployment to the left. The results of a follow-up experiment with vertically arranged cues and primes (reported in footnote 4) might reflect a further endogenous attentional bias toward the lower visual field that overrides exogenous cueing effects (e.g., Gawryszewski, Riggio, Rizzolatti, & Umilta, 1987; Spalek & Hammed, 2004).

Support for the endogenous bias account of the left–right asymmetry found in this study was provided by a study comparing IOR in English and Arabic readers (Spalek & Hammed, 2005). These authors replicated their prior observation of a left–right asymmetry in IOR with Canadian participants (Spalek & Hammed, 2004), and furthermore showed that the asymmetry was reversed in a group of Egyptian participants. Given the timing of trials used by Spalek and Hammed (much longer cue durations than in this study), it is likely that the left–right asymmetry they observed was driven by a bias to disengage more in a certain direction, rather than in terms of differences in how easily attention can be engaged in a given direction. In any case, the results of Spalek and Hammed (2005) are clearly in favor of the hypothesized role of reading habits on attentional biases.

Finally, this right–left language-driven asymmetry should be less evident with non-linguistic stimuli than with linguistic stimuli, and a recent subliminal cueing study of Mulckhuyse, Talsma, and Theeuwes (2007) is consistent with this idea. They used non-linguistic stimuli such as line orientations and showed subliminal IOR at both sides of the visual field. Further experimentation comparing linguistic and non-linguistic stimuli in the subliminal IOR paradigm, and involving languages that are read in different directions, will help to answer these important questions. The most important result of this study is that IOR has been found to modulate priming effects obtained from subliminally presented stimuli, thus demonstrating that this inhibitory attentional mechanism can affect unconscious processing.

[4] A follow-up experiment with 17 participants examined IOR for prime stimuli presented above or below centrally located targets, using the same stimuli and timing of events as in the main experiments. None of the main effects of interactions were significant, except for a trend toward an interaction between prime position and prime relatedness, $F(1,16) = 3.80$, MSE = 115.6, $p = .06$. Primes located above targets generated a significant priming effect, $F(1,16) = 5.31$, MSE = 121.8, $p = .03$, whereas primes appearing below targets did not produce priming, $F < 1$. Since cue validity did not influence priming, there was no evidence for IOR in this experiment.

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