Endogenous Attention and Lateral Interference

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Abstract

Lateral interference refers to the phenomenon that a target that is surrounded by other stimuli with a small interstimulus distance is more difficult to identify than a target that is surrounded by stimuli with a large interstimulus distance. In a few studies it was argued that the effect of lateral interference can be reduced when exogenously cued attention is already focused at the target-location which was ascribed to an effect of attention on early perceptual stages of stimulus-processing. However, the measures for lateral interference that were used in these earlier studies were all somewhat susceptible to influences from later stages of stimulus processing. To obtain more conclusive results with regards to the stage at which attention can modulate stimulus processing, measures derived from signal detection theory were used in the present study. Attention was manipulated by endogenous cues to prevent forward masking. As stimuli, circular arrays with a target at their center were used, interstimulus distance was varied between two values, and the endogenous cue was valid in 75% of the cases whereas it was invalid in 25% of the cases. No evidence for a reduction of lateral interference was found, what can be explained by differing efficiency of endogenous and exogenous cues at an early, perceptual stage of stimulus-processing.

Introduction

Lateral interference refers to the phenomenon that a stimulus which is surrounded by other stimuli with a short interstimulus distance is more difficult to identify than a stimulus which is surrounded by stimuli with a large interstimulus distance (Bouma, 1970; 1973). At more eccentric locations of the visual field, the effect of lateral interference is stronger; a decreased interstimulus distance also increases lateral interference (e.g. Bouma, 1970; Huckauf & Heller, 2004; Pelli, Palomares & Majaj, 2004). Two different types of mechanisms are considered to be involved in causing lateral interference, namely physiological restrictions of the visual system and attentional processes. As stated earlier by Van der Lubbe & Keuss, the physiological restrictions that play a role in lateral interference can be classified into two categories (Van der Lubbe & Keuss, 2001). The first category of restrictions explains why lateral interference is stronger at more eccentric location within the visual field. The receptive fields of cells in the fovea are smaller than the receptive fields of cells that are located more peripherally, furthermore the density of cones (the type of receptor cells which are responsible for accurate vision) is highest in the fovea and decreases with increasing eccentricity. The second category of physiological restrictions explains why a stimulus that is surrounded by distractors is more difficult to identify than a stimulus that is presented in isolation. Inhibitory connections exist between receptive cells that process neighboring areas of the visual field. So when a target appears close to a distractor in the visual field, processing of the distractor inhibits processing of the target (Desimone & Duncan, 1995). The second type of mechanisms that contribute to the decreased performance when a target is flanked by distrators are attentional processes. Several studies found that adding flankers to a target decreases performance, even when the flankers are completely irrelevant to the task and when the target-location is known in advance (e.g. Eriksen & Eriksen, 1974; Eriksen & St. James, 1986; Kahneman, Treisman, & Burkell; 1983).

This suggests that every flanking element automatically attracts attention and thereby interferes with target-processing (Van der Lubbe & Keuss, 2001). In this phenomenon, the distance between the target and the distractors does not play a role, the decreased performance when distractors are added is explained by attention being not longer focused on the target alone, but distributed over all elements, so the number of elements in an array, not eccentricity and interstimulus distance limit performance. This phenomenon is also referred to as attentional masking. Therefore when studying lateral interference, the number of stimuli in cued and uncued conditions should been held constant to make the two cueing-conditions comparable with regard to attentional masking (Van der Lubbe & Keuss, 2001).

Whereas lateral interference is an interesting phenomenon in itself, studying lateral interference could also yield new insights into the role of attention in stimulus processing. Lateral interference is considered to occur at an early, perceptual level of stimulus-processing (e.g. Pelli, Palomares & Majaj, 2004). If the effect of lateral interference was shown to be modified by attention, that would suggest that attention exerts its influence on stimulus-processing already at an early stage. That would be in accordance with neurophysiological studies which found that focused attention contrasts the receptive field of a cell around the attended target (Desimone & Duncan, 1995; Luck, Chelazzi, Hillyard, & Desimone, 1997) what suggests that attention operates at an early stage of stimulus processing. Further evidence for an effect of attention at early perceptual levels is that attention improves spatial resolution by enhancing target processing (Carrasco, Williams and Yeshurun, 2002). This effect of attention on performance is not limited to conditions in which a higher spatial resolution enhances performance but occurs also when higher spatial resolution decreases performance, so it is not just a general enhancement of performance through attention that has been observed in many different tasks.

In addition, attention was found to exert an influence on several processes that were thought to be pre-attentive. For instance, it was found that the detection of primitive object-features of targets suffered when the target was presented while attention was focused on a specific region elsewhere in the visual field (Atchley, Kramer & Theeuwes, 1999). Further phenomena that used to be ascribed to early, pre-attentional stages but have shown to be moderated by attention are among others luminance detection (Posner, Snyder & Davidson, 1980), motion perception (Cavanagh, 1999) and contour detection (Ito, Westheimer & Gilbert, 1998). Additional evidence for effects of attention on early stimulus-processing has been found by several studies that used scalp-recorded event-related brain potentials (ERPs) to investigate the relation between attention and stimulus processing and found that attention modulates stimulus-processing as early as at the primary visual cortex (e.g. Di Russo et al., 2003; Heinze et al, 1994; Hopfinger & Mangun, 1998, Hopfinger & Ries, 2005 Hopfinger & West, 2006; Martinez et al., 1999; Van der Lubbe& Woestenburg, 1997). In sum, there is accumulating evidence for an effect of attention on early stages of stimulus processing what suggests a relation between attention and lateral interference. This possible connection between attention and lateral interference was investigated by several earlier studies which yielded mixed results. Nazir (1999) investigated lateral interference by presenting squares with a small gap either at the left side, at the right side, at the top or at the bottom. These squares acted as targets and were either presented in isolation or flanked by four distractors, one at each side of the target. Presentation of these targets was either preceded by a cue (a dot) that appeared at the location where the target was to occur; or by eight dots that were displayed on an imaginary circle-line. The percentage of correct responses was used as a measure of performance. No evidence for an effect of attention on lateral interference was found. However, the study of Nazir has some methodological weaknesses that could account for its null finding. Firstly, a condition in which a target was flanked was compared with a condition with a target that was presented in isolation, as stated above; in that case the two experimental conditions are not comparable regarding attentional masking. Secondly, Nazir did not find any effect of cueing in any condition, so attention might not have been actually manipulated by the cue. Another study (Wilkinsons, Wilson & Ellemberg, 1997) investigated lateral interference with a change-detection-paradigm. Gabor patches were used as stimuli. They were arranged in a horizontally orientated array, the central element acted as the target. Participants were required to detect changes in contrast and orientation of the target. Distances between the target and the flanking elements were varied. As a measure for performance, change detection thresholds were used. To investigate whether attention improved performance, a cueing condition was added to the experiment. In this condition, the position of the target was indicated by an exogenous cue (either a vertical line element or two black squares above and below the target position) but no effect of cueing was found. However, as in the study by Nazir described above, Wilkinson did not find any cueing-effects, which leaves open the explanation that attention was not manipulated.

Scolari, Kohnen, Barton & Awh (2007) investigated lateral interference with an orientation detection task which required participants to indicate the orientation of the letter T that was presented either in isolation or flanked by two stimuli with varying interstimulus-distances. The target could appear to the left or to the right of fixation and its position was predicted by an exogenous cue that appeared at the target-location in one condition, whereas in the other condition, all possible target-locations were cued. Critical spacing, defined at the distance between target and distractor at which accuracy exceeded a predetermined criterion, was used as a measure for lateral interference. Higher accuracy was observed when the cue was presented at the target location, but the critical distances of the two cueing conditions did not differ.

Whereas the above mentioned studies did not find evidence for a reduction of lateral interference through focused attention, several other studies did. For instance, Van der Lubbe and Keuss found that pre-cueing attention to the location were a target was to occur could reduce the effect of lateral interference. In their study, a target was presented, flanked by several distractors. Prior to the presentation of the stimuli, exogenous cues indicated either the target location with different degrees of accuracy; or all possible target-locations, Furthermore, interstimulus distance was varied. When the exact location of the target was cued, the effects of interstimulus distance on reaction time and proportion of errors were reduced. Van der Lubbe & Keuss concluded that this is most likely due to an improvement of spatial resolution by focused attention what would pledge for an influence of attention on early perceptual processes (Huckauf & Heller, 2002). However, in their study percentage of errors and reaction times were used as measures for lateral interference, but both of these measure can be influenced by other factors than perceptual sensitivity, for example the type of the cue being used or decisional processes (e.g. Fan et al. 2002, Palmer, 1994), although only an attentional effect on perceptual sensitivity would indicate that attention modulates stimulus-processing at an early stage. Further evidence for an effect of attention on lateral interference was found by Huckauf and Heller, who compared identification of a target letter that was either presented in isolation or flanked by one letter at each side. To manipulate attention, they presented a rectangle at the location where the target was to occur. Presentation of the cue preceded the display of the target, followed the display of the target, or was simultaneous with the target. When the cue either preceded or followed the target, identification accuracy increased (Huckauf & Heller, 2002). However, they compared identification of a flanked and an unflanked target, was limits the conclusiveness of their results in the same way as in the study of Nazir (1992). Another study (Felisberti, Solomon & Morgan, 2005) that found evidence for a relation of attention and lateral interference was conducted by Felisberti and colleagues. They used arrays of Gabor patches as stimuli, the target was the central element of the Gabor patch and could appear at three different locations.The task required detection of the orientation of this target, while interstimulus distance was varied. In the cued condition, the location of the target was predicted by a line that extended from fixation at the center of the screen to the target-location, whereas in the uncued condition, three lines extended from fixation to all three possible target-locations. As a measure for performance, the accuracy with which the orientation of the target was detected was used. They found that cueing enhanced performance, in addition the critical distance, defined as the interstimulus distance at which performance exceeded a predefined threshold criterion; was reduced in the cued-condition. One possible methodological disadvantage of this study is the usage of accuracy as a measure for lateral interference. Accuracy can be increased not only due to higher sensitivity to the target, but also by other factors, for example cue type (e.g. Fan et al., 2002; Hübner, 1996).

Furthermore, Yeshurun and Rashal (2010) examined the relation between attention and lateral interference. They suggested that one reason earlier studies did not find convincing effects of attention on lateral interference might have been forward masking of the target by the cue. So they took measures to avoid masking, namely presenting the cue adjacent to the location where the target was to occur instead of the exact same location. As a target, they used the letter T whose orientation had to be identified either without any flanking stimuli or with distractors at different distances from the target. They found that pre-cueing attention to the target location enhanced accuracy and reduced critical spacing at all eccentricities (Yeshurun & Rashal, 2010). As already stated above, accuracy is not best suited to identify the specific attentional mechanisms that reduce lateral interference. Because critical spacing is derived directly from accuracy, it is also susceptible to factors other than perceptual sensitivity, so the stage of stimulus-processing on which attention enhances performance in this study cannot be determined.

In sum, the results of the studies described above are inconclusive and all of the studies have some methodological weaknesses that limit the soundness of their results.

Nonetheless, finding a reliable effect of attention on lateral interference would be highly relevant because of its implications for the stage of stimulus-processing at which attention operates.

Therefore, the present study will re-investigate the relation of lateral interference and attention with two important methodological changes. Firstly, whereas all earlier studies used exogenous cues to manipulate attention, the current study will use endogenous cues. One general disadvantage of exogenous cues is that they can induce forward masking of the target (e.g. Hübner, 1996), so performance is hampered because processing of the cue interferes with target-processing, but by using endogenous cues, we hoped to be able to avoid forward masking. Furthermore, the measures of performance that were used by earlier studies were not best suited to distinguish between different attentional processes that could account for the observed reduction of lateral interference through attention. Whereas it is assumed that an effect of attention on lateral interference implies that attention moderates stimulus-processing at an early level, the effect of attention can alternatively be attributed to the response selection stage. As stated by Palmer (1994) enhanced performance through focused attention does not necessarily have to occur at a perceptual level of stimulus processing. In the view of Palmer, all stimuli are processed up to the level of response selection. When attention is directed at the location of the target by cueing, the influence of distractors on the response is reduced (Palmer, 1994). To be able to distinguish between these alternative explanations, in the present study, a signal detection theory approach is used.Signal detection theory (e.g. Macmillan & Creeelman, 2005) assumes that in tasks that require detection or identification of stimuli, the actual response to a stimulus that is made depends on two processes. Firstly, a sensory process that is characterized by sensitivity; the ability of the observer to distinguish between different stimuli. Secondly, the decision process where the observer selects a response to the target based on a response criterion that reflects how likely or unlikely a specific response is made when being sure versus being very unsure about the presence or identity of the presented target. Signal detection theory has measures for sensitivity as well as for response criterion. So by using a signal detection theory approach, the present study attempts to shed light on the question if the potential reduction in lateral interference by attention indeed occurs at a perceptual stage of stimulus-processing. To induce lateral interference, targets will be presented at the center of a circular array of distractors. The display of these arrays is preceded by an endogenous cue that can be either valid or invalid. Furthermore, the distance between the target and the distractors will be varied between a smaller and a larger value.

Methods

Participants

Twenty participants cooperated in the study; 9 of the participants were male, 11 where female; the mean age of the participants was 22.4. Their handedness was assessed with the Annett Handedness Inventory (Annett, 1980), 18 of the participant were right handed, and two were left-handed. All participants reported normal or corrected to normal vision and signed an informed consent form prior to participating in the study.

Stimuli and task

Each trial started with the presentation of a white fixation point with a radius that amounted to 0.2° at the center of a black screen. After 1000 ms, the fixation point was replaced by an endogenous precue that was displayed at the center of the screen for 500 ms. The cue consisted of a diamond with a green half and a red half. Prior to each experimental block, participants were instructed to attend either to the side of the visual field that was indicated by the green half of the diamond or to side that was indicated by the red half of the diamond. This precue was followed by two circular arrays of letters with a SOA of 750 ms. One of the arrays was relevant and contained the target stimulus; the other one acted as a distractor and had to be ignored. The arrays were presented for 200 ms only and consisted of 12 letters that were distributed over an imaginary circle line with equal distances between the letters that amounted to 0.1° and a single letter at the center of each array. The letters on the circle line were randomly chosen out of the letters A, B, C, D, E, F, G, H, I, J, K, L and O and presented at a random position on the circle line. At the center of the relevant array, either the letter M or the letter W was displayed and served as a target stimulus whereas the letter at the center of the irrelevant circle was chosen randomly from the same pool as the letters on the circle-line. The two arrays were presented at an equal distance from the fixation point, with their center at 2.6° to the left or the right of fixationt. At each trial, the distance between the center of the array and the surrounding letters was varied between 0.25 ° and 0.63° randomly.

Apparatus

Stimuli were controlled with Presentation 14.9 software on one computer, and a second computer was used for data collection. Vertical and horizontal EOG were recorded with BrainVision Recorder 1.20 software, as well as the responses the participants made. Participants were seated in front of a screen on a comfortable chair in a dimly lit chamber where the distance between the participant's eyes and the screen amounted to 46cm.

Design and Procedure

Two independent variables were varied within subjects: cue-validity and interstimulus distance. On 75% of the trials, the cue that preceded the presentation of the target was valid, meaning that the location where the target was to occur was correctly predicted by the cue, whereas on the remaining 25% of the trials, the cue was invalid, so it predicted the target to occur on the opposite side of the location where the target actually occurred. Interstimulus distance was varied randomly at each trial between a large value of 0.63 °and a small value of 0.25°. In addition, one of the two possible targets, namely the letter M and the letter W, was presented randomly at each trial. The total experimental session took 1.5 hours per participant and started with four practice blocks of 20 trials. Prior to these practice blocks, participants were instructed to indicate whether they saw the letter M or the letter W by pressing the corresponding keys on a computer-keyboard which was the a-key for an M and the l-key for a W. At the beginning of each block, participants were instructed to attend either to the side of the screen the red half of the cue indicated or to the side of the screen where the green half of the cue pointed at; the color of the cue participants had to attend to was changed after completion of every practice block as well as after every experimental block. After the practice blocks were completed, four experimental blocks, each consisting of 160 trials were run.

Analysis

Trials which contained eye-movements during the presentation of the target stimulus were excluded from further analysis. The criterion that was used for eye-movements was 70μV. A Signal Detection Theory approach was used for data-analysis, whereby the measures that were used to operationalize sensitivity and response bias were calculated as described by Macmillan & Creelman (2005). Sensitivity was calculated by subtracting the proportion of trials on which a participant incorrectly indicated to have seen an M, when in fact a W was presented, also denoted as false alarms, from the proportion of trials on which the participant correctly indicated to have seen an M, also referred to as hits; resulting in a measure called d'. Response bias was operationalized by a measure called β, which was calculated as follows: The proportions of hits were added to the proportion of false alarms and mulitiplied by 0.5 and the negative value of d', subsequently, Euler's number was raised to the power of the result.

Results

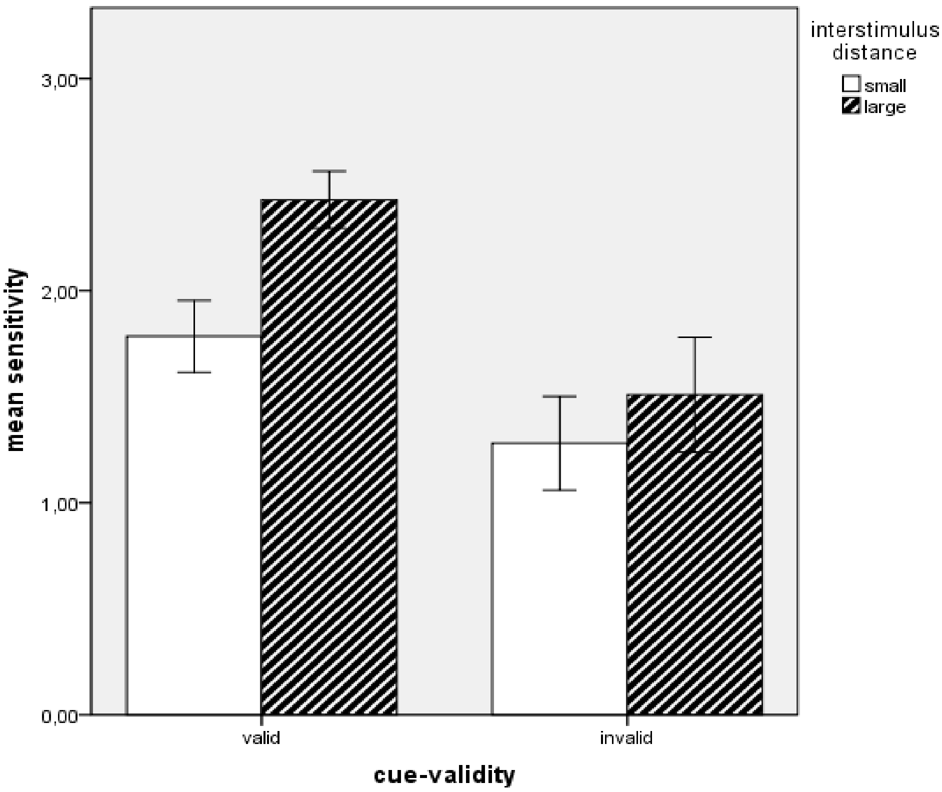
Eye-movements were detected on 2.1% of the trials. These trials were excluded from further analysis. Trials on which the response was slower than 1800 milliseconds or at which no response occurred at all were also excluded. Furthermore, two participants were excluded from analysis because their performance did not exceed chance level. For the remaining trials, MANOVAs were performed on d` and β.

Sensitivity (d')

The effect of target distractor distance on d´ was significant, $F(1, 17) = 4.505$, $p = 0.037$. Mean sensitivity in the condition with the large interstimulus distance amounted to 1.9 (standard deviation = 1.0), in the condition with the small interstimulus distance, mean sensitivity was

1.5 (standard deviation = 0.9). A significant effect on d' was also found for cue-validity, F (1, 17) =12, p = 0.001. Average sensitivity on validly cued targets was 2.1 (standard deviation = 0.7), for invalidly cued targets it was only 1.4 (standard deviation = 1.0). No significant interaction between target distractor distance and cue-validity was found, F (1, 17) =1.017, p=0.317. The results are summarized below in diagram 1.

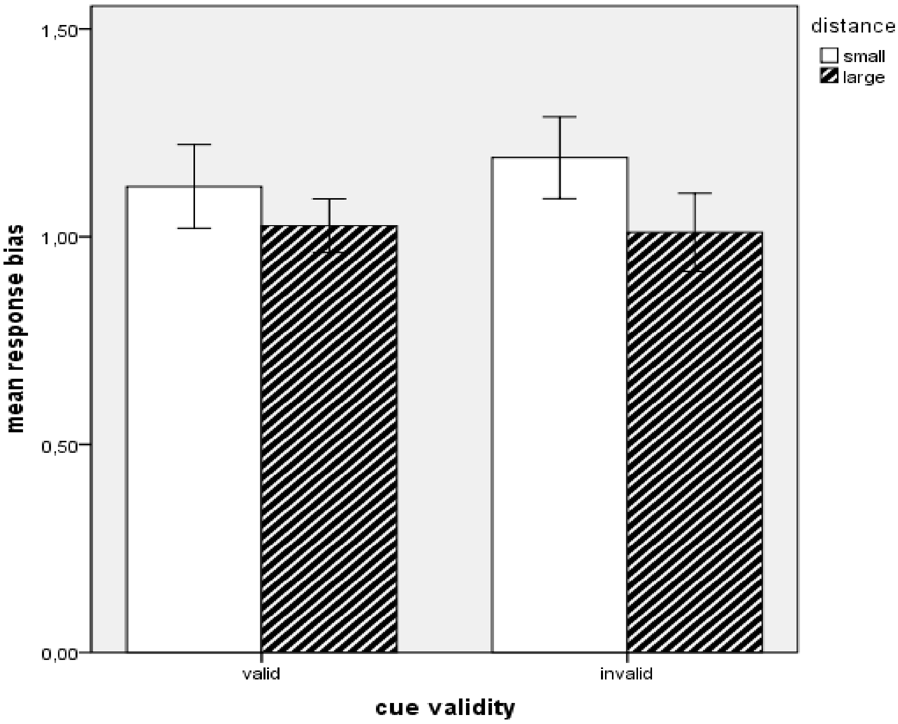
Diagram 1: Effects of cue-validity and interstimulus distance on sensitivity (d')



Response bias (β)

No significant effect of target distractor distance on β was found. F (1, 17) =2.283, p=0.135. Mean β in the condition with the large interstimulus distance amounted to 1.0 (standard deviation = 0.34), in the condition with the small interstimulus distance, mean β was 1.15 (standard deviation = 0.42S). Cue-validity did not have a significant effect on β, F (1, 17) =0.085 p=0.772. Average β on validly cued targets was 1.1 (standard deviation = 0.36) whereas on invalidly cued targets it was 1.1 (standard deviation = 0.41). No significant interaction effect of cue-validity and target distractor distance could be found, $F(1, 17) = 0.22$, $p = 0.639$. Diagram 2 gives a summary of the results.

Diagram 2: Effects of cue-validity and interstimulus distance on β



Discussion

The objective of the current study was to investigate whether attention reduces lateral interference. Our stud yielded three relevant results. Firstly, sensitivity for the target was lower at the small interstimulus distance and higher at the large interstimulus distance, thus we managed to replicate the effect of lateral interference (Bouma, 1970; Bouma, 1973). However, this effect of lateral interference was relatively small in our study, maybe even too small for a further reduction through attention. Secondly, when the target was preceded by a valid cue, sensitivity for the target was higher, thus sensitivity was affected by attention. Thirdly and perhaps most interestingly, no evidence for a reduction of lateral interference through attention was found in our study. That is in accordance with the findings of Nazir (1992), Wilkinson (1997) and Scolari et al. (2007). However, the conclusions that can be drawn from the studies of Wilkinson and Nazir are both limited by the same problem: they found no effect of attention in any condition at all, what could mean that they did not succeed at manipulating attention. Unlike these two studies, the present study found that attention increases sensitivity which rules out failure to manipulate attention as a possible explanation for the absence of an effect of attention on lateral interference. Whereas the study of Scolari et al. (2007) does not share this problem, exogenous cues were used to manipulate attention. In general, exogenous cues have the disadvantage that they can mask the target (e.g. Hübner, 1996). So, instead of enhancing performance, exogenous cues can lower performance because the processing of the cue interferes with target processing. Unlike the study of Scolari and colleagues, we used endogenous cues to prevent attentional masking of the target by the cue, thus attentional masking of the target is ruled out as a possible explanation for the absence of an effect of lateral interference in the current study. However, apart from studies that did not find an effect of attention on lateral interference, there are also studies that actually did find this effect (Felisberti, Solomon & Morgan, 2005; Huckauf & Heller, 2002; Van der Lubbe & Keuss, 2001; Yeshurun and Rashal, 2010). The lack of evidence for an effect of attention on lateral interference in the current study contradicts the findings of these studies. However, there are two important differences between the current study and earlier studies that could explain these conflicting findings. Firstly, in the present study, d' was used as a measure for sensitivity. This measure reflects perceptual sensitivity to a stimulus without confounding influences of decisional processes (Macmillan & Creelman, 2005). In contrast, the measures that were used by earlier studies e.g. accuracy and reaction time might be more susceptible to an influence from factors other than sensitivity (e.g. Palmer, 1994; Fan et at., 2002). The second relevant difference between previous studies and the present study is that all earlier studies used exogenous cues to manipulate attention whereas in the present study, endogenous cues where used. Originally, we decided to use endogenous cues to prevent forward masking of the target by the cue. However, whereas studies that manipulated attention with exogenous cues did find an effect of attention on lateral interference, this effect was not found in the present study where endogenous cues were used. That might reflect differences in endogenous and exogenous mechanisms of attention. More specifically, it suggests that endogenous attention might operate at later stages of stimulus processing compared to exogenous attention. Numerous studies that investigated the effect of endogenous attention on stimulus-processing by measuring scalp-recorded event-related brain potentials (ERPs) found that the earliest ERP-component that was moderated by attention was the P1, which is generated by the extrastriate cortex (e.g. Di Russo, 2003; Heinze et al., 1994; Martinez et al., 1999). Other studies used ERPs to investigate the effect of exogenous attention on stimulus processing and found an attentional modulation of the P1 component (e.g. Hopfinger & Mangun, 1998; Hopfinger & Ries, 2005, Van der Lubbe & Woestenburg, 1997). So the earliest ERP component that was affected in these studies was the P1, a finding that applied to both endogenous and exogenous attention alike. Considering the results of these studies, it seems unlikely that differences in the mechanisms of endogenous and exogenous attention can explain the findings of the present study. However, Hopfinger and West (Hopfinger & West, 2006) used ERPs to investigate interaction between effects of endogenous and exogenous attention on stimulus-processing. In their study, an uninformative exogenous cue and instructive endogenous cues were used. Participants were instructed to attend to the location that was indicted by the endogenous cue and to respond only to targets that occurred at this location, targets appearing at different locations had to be ignored. The endogenous cue was then replaced by an uninformative exogenous cue. Following the exogenous cue a checkerboard which was either vertically or horizontally orientated was presented. A response was required from participants only when the checkerboard was vertically orientated and appeared at the location that had been indicated by the endogenous cue. The P1 component that was elicited by processing of the target was enhanced when the exogenous cue had appeared at the target-location regardless of the location on which endogenous attention was focused. From these findings, Hopfinger and West (2006) concluded that although both endogenous and exogenous attention enhance ERP-components as early as P1, early stages of processing are dominated by exogenous attention. This suggests that exogenous attention might enhance perceptual sensitivity more efficiently at early stages of stimulus processing what could explain why exogenous attention was found to reduce lateral interference whereas the present study found no evidence of a similar reduction of lateral interference using endogenous cues.

Next to sensitivity, the present study also investigated response bias (β). In contrast to sensitivity, response bias was affected neither by interstimulus-distance nor by attention, so our data is not in accordance with models of attention that ascribe the effect of attention to the response-selection stage of stimulus-processing (e.g. Palmer, 1994). In sum, no evidence for reduction of lateral interference through focused attention was found in the current study, this could be explained by differing efficiency of endogenous and exogenous attention at early stages of stimulus-processing.

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