

Cueing the location of a distractor: An inhibitory mechanism of spatial attention?

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ABSTRACT

Presenting an irrelevant distractor increases reaction times to a target. The current study shows that cueing the location of an upcoming 'distractor' can help to reduce the effects the distractor has on target processing. It is hypothesized that this reduction is due to the active inhibition of the cued location. In two experiments in which the location of the distractor was cued in advance, a reduced effect of the distractor on target-processing was observed. Analyses indicated that this effect was most likely caused by inhibition of the distractor location. The present findings suggest that inhibition plays an important role in visual-spatial selection processes and that this inhibitory mechanism can be controlled in a top-down fashion.

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1. Introduction

Our capacity-limited brain is not equipped to dealing with the vast amount of sensory information that is presented to us at any given time. Therefore, a selection that separates the relevant from irrelevant information has to be made, allowing goal-directed behavior. Numerous studies have shown that focusing attention on locations or objects in the visual field improves this selection process (Luck, Hillyard, Mouloua, & Hawkins, 1996; Posner & Petersen, 1990; Theeuwes, 1989; Theeuwes & Van der Burg, 2007), which has led to the conclusion that attention is the necessary mechanism required for selection. When advance information regarding the location of relevant information in the visual field is available, attention can be deployed to this location prior to the actual presentation of relevant information. In a series of now classic experiments (Posner, 1978; Posner, 1980; Posner, Davidson, & Snyder, 1980; Posner, Nissen, & Ogden, 1978) it was shown that performance in detecting or discriminating a target significantly increased when the location of the target was previously cued. In a typical cueing task, participants are instructed to respond to the appearance of a target stimulus by making a key-press. In one variety of this task, called "endogenous", a central cue (typically an arrow) points to a possible target location, thereby allowing the participants to focus their attention on that location. After cue presentation, the target will appear at the cued location (valid) in the majority of the trials, but will sometimes appear at an uncued loca-

tion (invalid). The typical finding is that participants tend to respond faster and with higher accuracy to the target if it is presented at the cued location than when it is presented at the uncued location. These results reveal a benefit of location-cueing: focusing attention on the cued location enhances processing of the target stimulus, which results in faster responses and higher accuracy.

Even though most studies have focused on cueing an upcoming target location, recently, a number of studies have begun to investigate the effects of cueing the location of an upcoming distractor (Ruff & Driver, 2006; Van der Stigchel, Heslenfeld, & Theeuwes, 2006; Van der Stigchel & Theeuwes, 2006). The general idea behind these studies is that advance knowledge of the location of an upcoming distractor can help to reduce the interference of this stimulus on target-processing. Previous research has shown that when an irrelevant distractor is presented with a target stimulus, the capture of attention by the distractor impoverishes processing of the target as reflected by slower reaction times to the target (e.g. Schreij, Owens, & Theeuwes, 2008; Theeuwes, 1992). Moreover, in a study by Theeuwes, Kramer, Hahn, and Irwin (1998), it was shown that the eyes can also be captured by a new-appearing irrelevant distractor.

One of the mechanisms thought to be responsible for a possible reduction of interference is inhibition of the distractor location. In an eye movement study by Van der Stigchel and Theeuwes (2006), participants were informed whether and where a distractor would appear. Participants were presented with a central cue consisting of a short arrow pointing towards the location of a possible distractor (80% probability) and a long arrow pointing towards the target

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location. When the target appeared, participants were instructed to make a speeded eye movement towards the target location. The rationale behind this study was that participants could actively inhibit the distractor location on the basis of a top-down expectancy of where the upcoming distractor would appear. The results of this study showed that by cueing the location of the distractor in advance, the eye movement towards the target location was affected, showing a trajectory which deviated away from the distractor location even when the distractor was absent. Because these deviations away from the distractor location have been attributed to active inhibition of this location (Sheliga, Riggio, & Rizzolatti, 1994; Tipper, Howard, & Jackson, 1997), these results provide evidence for the idea that participants were actively inhibiting the distractor location on the basis of the distractor cue, even in trials in which the distractor did not appear.

The inhibition of irrelevant information is not only reflected in eye movement trajectories, but has also been found in a number of behavioral studies (e.g. Cave & Zimmerman, 1997; Wühr & Frings, 2008). In the study by Cave & Zimmerman, it was found that distractors presented close to the focus of attention received more inhibition than distractors presented further away. In their dual-task study, participants were instructed to give an unspeeded response reporting the presence or absence of a target letter within a circular array of (otherwise) non-target letters. In 50% of the trials a probe would appear after the presentation of the search array and participants would make a speeded response to the appearance of the probe. The probe could appear at a location previously occupied by either a target or a distractor letter. The results showed that reaction times to the probe were the fastest, when the probe was presented at the target location. However, slowest reaction times were observed for probes appearing at distractor locations with the least spatial separation between target and distractor, reflecting an inhibitory region surrounding the attended target location.

In a similar line of research, it was found that probes presented close to salient stimuli (feature singletons) were inhibited, resulting in lower probe discrimination sensitivity (d') at short distances from the feature singleton (Mounts, 2000a). Participants were shown a stimulus array containing multiple figure eight stimuli including one item that was made more salient (the singleton). The increased saliency of the singleton ensured an attentional focus at the singleton's location. After presentation of the search array, a probe was presented at a variable distance away from the singleton. When the probe was presented close to the salient item, d' was significantly lower than when the probe was presented further away, again reflecting the inhibitory surround of the focal point of attention. Importantly, inhibition of the probe location decreased with an increasing singleton–probe distance. In a follow-up study by Mounts (2000b), it was reported that the inhibitory component is attentionally in origin and can be top-down controlled by changing the participants' attentional set. When the target was a conjunction of features, this circle of inhibition disappeared and the color singleton itself became inhibited. Therefore, it is claimed that inhibition is at least up to a certain extent under top-down control.

Inhibition surrounding the focus of attention has been described as “localized attentional interference” and is more thoroughly investigated in a number of different studies (e.g. McCarley & Mounts, 2007; McCarley, Mounts, & Kramer, 2007; Mounts & Tomaselli, 2005). Importantly, these studies show that selective attention is not merely accomplished by enhancing the neural response coding for the attended location, but that inhibition of the surrounding area degrades the processing of items presented in this region. Both enhancing the attended location and the inhibition of the surround result in a bias favoring the attended location.

In a recent fMRI study by Ruff and Driver (2006), participants performed a speeded discrimination task in which an arrow was presented pointing to the location of the upcoming target. In the experimental blocks, the color of the arrow (either red or green) informed the participants whether a distractor would be present or absent. If a distractor was present, it always appeared at the opposite side of the screen. In control blocks, the target arrow did not provide information whether a distractor would appear or not. This study showed that participants were generally slower when a distractor was present than when it was absent. However, on trials in which the upcoming distractor was cued, reaction times were faster compared to trials in which this information was not available. Another important finding of this study was that when there was advance knowledge that a distractor would not be presented, reaction times were similar to those found in the control block in which distractors were absent. This suggests that the differences found in the cued distractor present condition are not attributable to an increase in arousal or other general effects. According to Ruff & Driver, advance knowledge of an upcoming distractor helps counteract the impact of this stimulus, resulting in faster responses to the target. However, they do not explain the mechanisms responsible for the decrease in detrimental effects caused by the distractor. The fMRI data showed that when a distractor was validly cued, activation in the corresponding hemisphere (which was never the hemisphere corresponding to the processing of the target) arose, suggesting that an active process was taking place at the cued distractor location. Based on the inhibitory effects found in eye movement studies, it seems plausible that the effects found by Ruff & Driver are caused by top-down inhibitory effects, even though this explanation was not suggested in their paper. Cueing the location of the upcoming distractor may have resulted in active inhibition of the cued location, allowing for faster target detection.

Alternatively, the cue may function as a means for the participant to help distinguish which of the presented items is the target and which is the distractor. In general, looking for a target involves comparing all items, until a pre-defined shape has been detected. When a cue is presented indicating the location of an irrelevant stimulus, this comparison is no longer necessary for this irrelevant stimulus. In this account, the cue does not evoke inhibition at the distractor location, but helps the participant select the target from the presented items. This account does not necessarily invoke inhibitory processes at the distractor location.

The present study was set out to determine whether cueing the location of an upcoming distractor would evoke top-down inhibition of this location diminishing the effect of the presented distractor. The question arises whether it is possible to actively inhibit the distractor location purely on the basis of advance knowledge. In the first experiment, the location of the distractor was cued on half the trials. When a cue was present, a distractor would appear at the cued location on half the trials. In the remaining trials, a distractor was not present. Participants were instructed to respond to the target, while making use of the distractor cue. Importantly, there were always four possible target locations, making the exact target location unknown. This design allows examining whether inhibition can occur as a result of advance information about the location of the distractor, independent of target cueing.

2. Experiment 1

In Experiment 1, we investigated whether cueing the location of a distractor can improve target-processing. Participants were asked to judge the orientation of a target stimulus by making a two-choice response. At the start of each trial, the possible distractor location was indicated by a central cue. Participants were instructed to actively use this information. The aim of this study

was to investigate whether locations can be inhibited on the basis of advance knowledge of the possible distractor location. If fewer attentional resources are allocated to the distractor, this should result in a faster response to the target.

2.1. Method

2.1.1. Participants

Twelve healthy participants (eleven female, mean age = 20.9 yrs) served as paid volunteers. All participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment.

2.1.2. Stimuli

All stimuli were presented in grey on a black background, with the exception of the cue which was presented in an equiluminant type of red (11.4 cd/m). The target consisted of either a capital 'T' or an inverted capital 'I', whereas the distractor always took the shape of the two different targets superimposed, resulting in an 'I' shaped figure. Target and distractor were presented at a visual angle of 5.3° from the central fixation point and at a distance of either 10.6° or 7.5° from each other, depending on the location of both stimuli. The size of the target and distractor was 0.76° by 0.99° . The cue screen consisted of four arrows of which one could turn red, indicating the distractor location. All arrows subtended a visual angle of 1.14° by 0.69° and were presented 1.07° from the center of fixation. Stimulus presentation and response collection were controlled using E-Prime 1.1 (Psychology Software Tools, www.pstnet.com), running under Windows XP on an Intel Pentium 3 pc. A 19" CRT monitor was used to display the experiment.

2.1.3. Procedure

Participants were seated in a dimly lit cabin at a viewing distance of 75 cm from the monitor. Fig. 1 shows the time course of a typical trial. First, a fixation screen was presented, containing the four centrally presented arrows with a fixation point in between. The arrows pointed to the four possible target and distractor locations.

Participants were instructed to maintain fixated on the centrally presented fixation point during the entire trial. After 500 ms, on half the trials one of the arrows turned red, indicating the location of a possible distractor. When a location was cued, a distractor could appear at that location on 50% of the trials, whereas on the other 50% of the trials no distractor was present. In the event that the cue was not presented, a distractor could still appear on half the trials at one of the four locations. On the remaining trials only the target was displayed. The cue, which was presented for 1500 ms, was 100% indicating that the target would not appear at the corresponding location. If no cue was presented, the four arrows remained on screen for an additional 1500 ms in order to obtain similar time courses for the cue-present and cue-

absent trials. The target and distractor would remain on screen for a maximum duration of 1500 ms, but would disappear when a response was given, after which a black screen was presented for 1000 ms, signaling the start of the next trial. The entire experiment consisted of five blocks of 96 trials each, the first block being used as a practice block. Target and distractor locations were balanced over blocks. Participants responded as fast as possible to one orientation of the target with their left hand, while for the other orientation the right hand was used. The response hand was counterbalanced over participants.

2.2. Results

Reaction times smaller than 200 ms and larger than 1200 ms (0.69%) and reaction times on incorrect responses (4.92%) were excluded from the analysis. No significant effects of the experimental manipulations were found in the error scores.

A repeated measures analysis of variance (ANOVA) with "cueing" (distractor cued vs. distractor uncued) and "distractor" (distractor present vs. distractor absent) as factors revealed a main effect of cueing and distractor. Participants responded faster to the target when the location of the possible distractor was cued than when it was not cued (cued: mean = 568 ms, uncued: mean = 585 ms; $F(1,11) = 13.99$, $p < 0.005$; $MSE = 254.05$). Furthermore, participants were slower when a target was accompanied by a distractor than when a target was presented alone (distractor present: mean = 613 ms, distractor absent: mean = 540 ms; $F(1,11) = 59.24$, $p < 0.001$; $MSE = 1090.55$). Importantly, there was a significant interaction between cueing and distractor ($F(1,11) = 5.74$, $p < 0.05$; $MSE = 244.62$). Fig. 2 shows that the distractor evoked a larger increase in reaction time when the cue was absent compared to that when the cue was present. Indeed, additional t-tests showed that participants benefited from a cue when a distractor was present ($t(11) = 3.41$, $p < 0.01$), but not when a distractor was absent ($t(11) = 1.63$, $p > 0.10$).

Even though these results can be fully explained by an inhibition mechanism, reducing the interfering effects of the distractor, an alternative explanation might also account for the results. It could have been that the distractor cue functioned as a target cue, cueing the three remaining target locations. This would have allowed participants to shift their attention towards the three remaining locations or make an eye movement away from the cued location, instead of inhibiting the distractor location. In this explanation, the mechanism responsible for the reduced influence of the distractor would not be inhibitory in nature, but excitatory.

To rule out this alternative account, we compared the effects of the cue on target-only trials. If participants used the distractor cue to attend to the remaining target locations, this should result in faster responses to the target when the distractor cue was present compared to when no distractor cue was presented. As reported above, in distractor-absent trials, there was no difference between

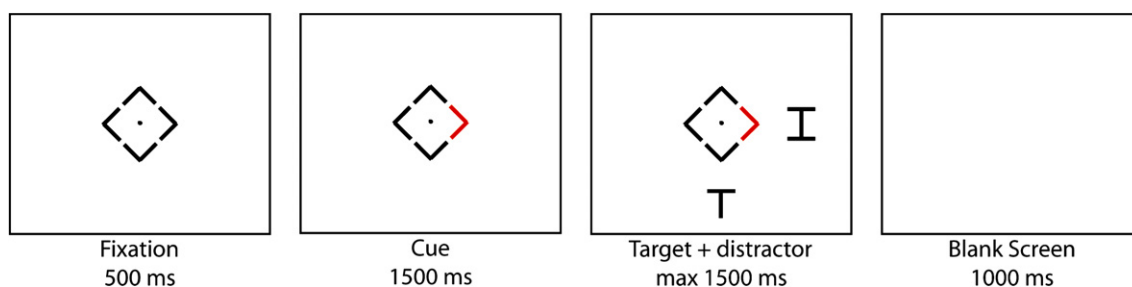


Fig. 1. Time course of a typical trial in Experiment 1. Participants were presented with four arrows of which one could turn red 2000 ms after trial onset, indicating the location of the upcoming distractor. Participants responded to the identity of the target by pressing a key as fast as possible. Both the cue and the distractor could be present or absent, resulting in a 2×2 design.

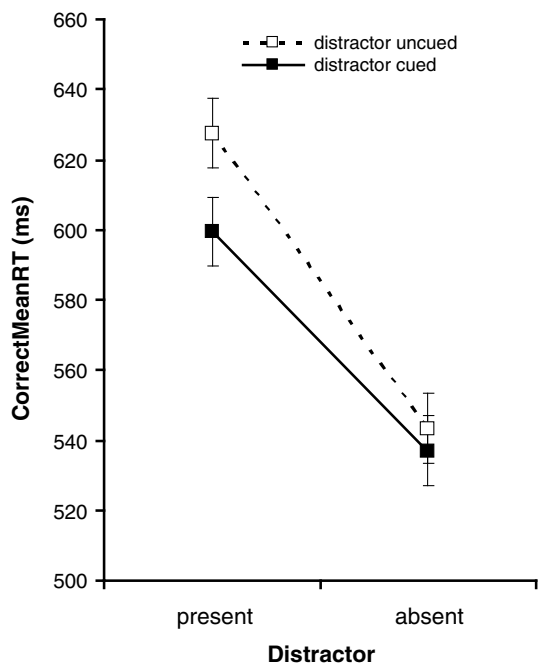


Fig. 2. Mean response time (in ms) of Experiment 1, shown in two conditions. When a cue is present the distractor effect is reduced. Error bars represent 95% confidence intervals for the interaction between cueing and distractor presence, corrected for within-subjects designs (Loftus & Masson, 1994).

the trials in which the distractor location was cued and the trials in which the distractor location was not cued. Moreover, if participants shifted their attention away from the cued location, it would result in a difference between the targets which were presented relatively close to the cued location and the targets presented further away from this location (7.5° and 10.6° of visual angle, respectively). An ANOVA with distractor (distractor present vs. distractor absent) and distance (target close vs. target far) as factors revealed no significant effect of distance ($F < 1$). Again an effect of distractor was found ($F(1,11) = 32.70$, $p < 0.001$; $MSE = 1522.74$), but no significant interaction between distractor and distance was observed ($F < 1$). Therefore, a shift of attention away from the cued location as an explanation for the observed effect seems unlikely.

2.3. Discussion

In cueing studies, it is often found that a target stimulus is processed faster when information about the target location is known in advance. In Experiment 1, we showed that cueing the location of a distractor diminishes the interfering effects of this distractor. We first replicated the distractor effect, showing that the presence of a distractor severely deteriorates performance on the target. We further showed that by cueing the location of a distractor, providing participants with advance knowledge of an interfering stimulus, the detrimental effects caused by the distractor decreased. Our results can be fully explained by a model in which inhibition is the main mechanism responsible for the results. By inhibiting the cued location, the information presented at this location does not receive the amount of attentional resources it would have received when a cue had not been provided. This lack of attentional resources results in less competition caused by the distractor, thereby leaving the target automatically with more available resources, making the processing of this stimulus more efficient.

However, an alternative explanation can account for the observed effects as well. It is possible that participants do not use the cue to inhibit the distractor but to distinguish which of the presented items is the actual target. If the cue is absent, partici-

pants can only find the target by distinguishing between the shapes of the presented items. When a cue is presented this is no longer necessary, because the cue provides sufficient information about which of the presented items is the target. In this situation, no visual search is necessary because the target is the only element not presented at the cued location. This explanation might also account for the lack of inhibition when no distractor is present. When no distractor is present, there is also no ambiguity as to which item is the target. Because of the lack of ambiguity, the information provided by the cue is not necessary; hence the information provided by the cue is only used when a distractor is actually presented. Thus, the results of Experiment 1 could have been established either due to inhibition of the distractor location or due to the presence of a cue, reducing the need to search for the target stimulus. The set-up of Experiment 1 does not allow a separation of both mechanisms, but shows that advance knowledge of a distractor location reduces the interfering effects of items presented at that location.

To differentiate between the proposed inhibition account and the above-mentioned ‘ambiguity’ account, a second experiment was conducted in which information at the distractor location automatically influences target-processing. For these ‘automatic’ distractors, there is always ambiguity except when information is actively suppressed. Therefore, a flanker-like design was adopted because it is known that compatible and incompatible flankers presented at non-target locations automatically interfere with target-processing, despite prior information about the target and distractor locations (Eriksen & Eriksen, 1974; Miller, 1991). If the inhibition account is viable, the information at the cued location should disrupt target-processing less, because the compatible and incompatible distractors are actively suppressed. If the ambiguity account is valid, the distractor-processing still occurs and the distractors will therefore influence target-processing.

Furthermore, to exclude the possibility that the absence of an inhibitory cueing effect in the distractor absent condition in Experiment 1 is due to a single target appearing as an abrupt onset, allowing this item to capture attention and dissolve the inhibition quickly, multiple elements were presented on every trial in Experiment 2. Besides a target and a distractor, neutral stimuli were presented which do not interfere with target-processing.

3. Experiment 2

To differentiate between the two proposed mechanisms, a second experiment was run in which the location of upcoming distractors was cued in a flanker-like task. A distractor accompanied the target on every trial and could either be compatible or incompatible with the target.

3.1. Method

3.1.1. Participants

Fourteen healthy participants (nine female, mean age = 23.4 yrs) served as paid volunteers in this experiment and none of them had participated in Experiment 1. All participants had normal or corrected-to-normal vision.

3.1.2. Stimuli

All stimuli were presented on a dark grey background in a lighter shade of grey (12.08 cd/m) with the exception of the cueing arrow(s) which could turn red (7.96 cd/m). Targets consisted of the capital ‘B’ or ‘F’, whereas the distractor was always indicated by the lower case letter ‘b’ or ‘f’. Because of the response compatibility between the distractor and the target, it was thought that the distractor would have a strong effect on target performance.

Neutral stimuli consisted of randomly selected upper or lowercase letters “x” and “k”. Distances between the fixation point and stimuli were similar to those in Experiment 1. The letter stimuli subtended a visual angle of 0.99 by 1.25°.

3.1.3. Procedure

The time course of this experiment was similar to Experiment 1. The fixation screen, which was presented for 500 ms, consisted of four centrally presented arrows, pointing towards the possible target and distractor locations, with a central fixation point in between. In 50% of the trials, all arrows turned red and thereafter the elements were presented. In the remaining 50% of the trials, only one arrow turned red, indicating the location of the upcoming distractor. A search display always consisted of a target, a distractor and two neutral stimuli. The different targets corresponded with two different response keys on a standard keyboard and response hand was counterbalanced over participants. Two thousand ms after cue presentation, the search display appeared and the participant was instructed to respond to the target as fast as possible. The target and distractors remained on screen for a maximum duration of 1500 ms, but disappeared when a response was given.

The distractor was compatible with the target in 50% of the trials and incompatible on the remaining trials. Note that again, the target never appeared at the cued location. The experiment consisted of three blocks of 96 trials, preceded by a short practice block of 48 trials.

3.2. Results

Reaction times smaller than 200 ms and larger than 1200 ms (2.38%) and reaction times on incorrect responses (6.12%) were excluded from the analysis. No significant effects of the experimental manipulations were found in the error scores.

A repeated measures analysis of variance (ANOVA) with “compatibility” (distractor compatible vs. distractor incompatible), “cueing” (distractor cued vs. distractor uncued) and distance (“close” vs. “far”) as factors showed a main effect of compatibility. Participants responded faster to a target when it was flanked by a compatible distractor compared to an incompatible distractor (compatible: mean = 647 ms, incompatible mean = 677 ms; $F(1,13) = 29.64$, $p < 0.001$; $MSE = 844.60$). A main effect of cueing was observed, indicating that participants respond faster when a cue was presented, than when the cue was absent (cue present: mean = 640 ms, cue absent: mean = 685 ms; $F(1,13) = 29.94$, $p < 0.001$; $MSE = 1827.32$). A main effect of distance was found, demonstrating that participants were faster to respond when target and distractor were presented further apart (distance close: mean = 669 ms, distance far = 656 ms; $F(1,13) = 5.20$, $p < 0.05$; $MSE = 895.47$).

As can be seen in Fig. 3, the compatibility effect was larger in the distractor-uncued condition compared to the distractor-cued condition, indicated by a significant interaction between Cueing and Compatibility ($F(1,13) = 9.73$, $p < 0.01$; $MSE = 673.93$). Post-hoc testing showed that in both the cued and the uncued conditions the compatibility effect was significant (Cued: $F(1,13) = 4.82$, $p < 0.05$; $MSE = 341.37$; Uncued: $F(1,13) = 56.35$, $p < 0.001$; $MSE = 270.83$). No other significant interactions were found in this experiment.

3.3. Discussion

Similar to Experiment 1, cueing the location of a distractor decreased the effect of the distractor on target-processing. Because the nature of the distractor was such that it would automatically influence target processing, we were able to dissociate between two possible explanations. If the ambiguity account was valid, dis-

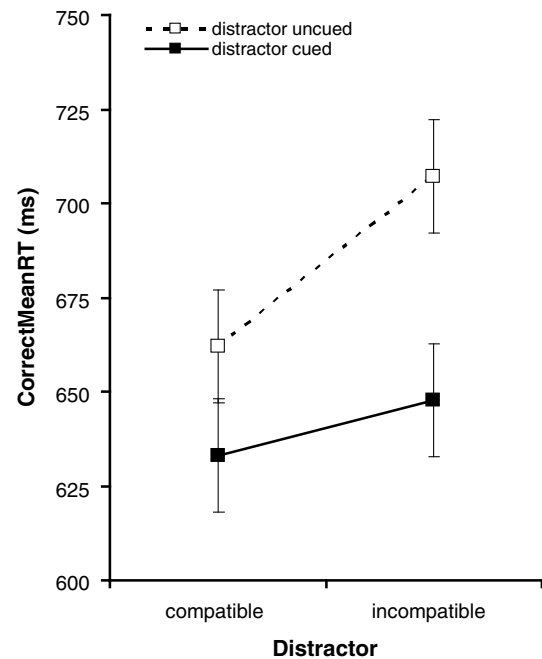


Fig. 3. Cueing the location of a flanker-like distractor results in a reduced compatibility effect. Error bars represent 95% confidence intervals for the interaction between cueing and compatibility, corrected for within-subjects designs (Loftus and Masson, 1994).

tractor processing should still occur and therefore influence target-processing. However, if the cue allows an active inhibition of the distractor, the interference it causes should be reduced. The data support the latter explanation, because the compatibility effect was very much reduced when the distractor location was cued in advance.

4. General discussion

Most cueing studies have focused on providing participants with advance knowledge of the location of an upcoming target stimulus. In the present study, it was not the location of the target that was cued, but the location of an upcoming distractor. The results of Experiment 1 showed that cueing the distractor location led to faster response times to the target. This shows that the advance knowledge of the distractor location diminishes the interfering effect of the distractor suggesting an active inhibition of the distractor location. However, the results could also be explained by an alternative account in which ambiguity about the target is reduced because of the presence of the distractor cue.

Experiment 2 was conducted to separate the two proposed accounts. Experiment 2 showed that cueing the location of a distractor in a flanker-like experiment resulted in a reduced compatibility effect between the target and distractor. Because compatible distractors on a non-target location automatically interfere with target-processing despite prior information about the target and distractor locations (Eriksen & Eriksen, 1974; Miller, 1991), the strongly diminished compatibility effect makes a strong claim for an inhibition account. The ambiguity account cannot explain the results of Experiment 2. The cue can help to distinguish between target and distractor, yet when the presented distractor automatically influences target processing, inhibition of the distractor seems the most likely explanation of the current results. Whereas the ambiguity account does not seem to explain the results of Experiment 2, it can still explain part of the results of Experiment 1.

The present study provides evidence for the existence of an inhibitory mechanism of attention which can be controlled top-down, similar to the excitatory system used when a target location is cued. In the experiments described in this study, the location of the target was not cued, which suggests that the inhibitory mechanism can be controlled, independently of the excitatory mechanism. The notion of two different functional systems for, respectively, excitation and inhibition is supported by an ERP study by Van der Stigchel et al. (2006), in which both target and distractor locations were cued in advance. The target and the distractor were endogenously cued by differently colored arrows, reflecting the possible location of target and distractor. Participants were instructed to make an eye movement towards the target as fast as possible. The results of this study showed an early component called “right-lateralized inhibition positivity” (RLIP), hypothesized to reflect cue-induced inhibition.

Ruff and Driver (2006) examined differences in brain activity on trials in which distractors were cued, compared to trials in which distractors were uncued, using fMRI. Their results showed significant attentional modulation exclusively in the occipital lobe, contralateral to the cued distractor side, while no modulations were found contralateral to the cued target side. These findings support the notion that cueing the distractor location does not enhance target activation, but rather inhibits the locations at which interfering information is expected.

Although we sought out to disentangle inhibition at the cued distractor location from excitation at the target location, we do not claim that these mechanisms do not act concurrently. Inhibition and excitation may be intimately linked and may act concurrently in order to enhance the processing of relevant information in a noise-filled environment. Moreover, at a neural level a closely linked connection between excitation and inhibition can be observed. For instance, in the cerebral cortex a distinction can be made between excitatory neurons, such as pyramidal cells, and inhibitory cells. However, both types of cells can be found active concurrently during spatially selective tasks (for an overview of the role of inhibition in neural and cognitive control mechanisms, see Houghton and Tipper (1996)). So, while we have solely focused on inhibitory mechanisms, we do not claim that excitatory mechanisms do not play a role in reducing the interfering effects of a distractor. The crucial finding is that the effects of a distractor can be eliminated by advance knowledge of its location. We believe that the current study provides sufficient evidence to claim that inhibition is one of the mechanisms involved.

It may be possible to explain the current results in terms of “tagging” processes. Tagging of irrelevant information was proposed by Neill, Valdes, Terry, and Gorfein (1992) as an alternative hypothesis to explain negative priming. Previously presented items which did not require a response could be tagged as irrelevant items. Whenever this item was later presented as a target, the tag would be retrieved resulting in a slower response to the target. In the current study a distractor always interfered with target-processing and never needed to be responded to, therefore a “no-response” tag could accompany the internal representation of the distractor. Subsequently, whenever the distractor was presented, the tag was retrieved from memory, suppressing the interference caused by the distractor. This would facilitate search and result in faster reaction times in response to the target. This explanation might not necessarily involve an inhibitory component. However, if distractor stimuli were tagged in this study, it would not matter whether the distractor would be preceded by a cue or not. In the current study, it is found that cueing the location of a distractor has an effect on target-processing. An explanation in terms of tagging therefore seems unlikely.

Inhibition of irrelevant information as the responsible mechanism for better target performance has been proposed before. In

a series of experiments by Cepeda, Cave, Bichot, and Kim (1998), in which a probe stimulus was shown at a location previously occupied by a target or a distractor or at an empty location, it was shown that probes were processed slowest at locations in which a distractor was previously displayed. Cepeda and colleagues make a strong case for inhibition of the distractor location by showing that response times to probes at previously empty locations produced the fastest reaction times, suggesting that distractor locations were indeed inhibited.

Furthermore, in a single-cell study by Moran and Desimone (1985), monkeys were taught to shift their attention to one of two stimulus locations within the receptive field of a single neuron in extrastriate area V4. At both stimulus locations, a different stimulus was presented, one which elicited a high neural response, whereas the other elicited no neural response. In blocked order, monkeys focused their attention on one of the two stimuli. It was found that the neural response to the unattended stimuli was severely attenuated, whereas the response to the attended stimuli remained largely unaffected independently of the presence or absence of the irrelevant stimulus. Based on these results, a filtering account of attention was proposed: The information presented at the focus of attention is processed, whereas the irrelevant information presented in the visual field is actively suppressed. In this model, inhibition of irrelevant information benefits the target-processing as opposed to the enhanced processing of the target location as found in classical cueing studies. The results found in the single-cell study by Moran & Desimone and the fMRI study by Ruff and Driver (2006) align with the data found in the present study. Inhibition of irrelevant information causes the relevant information to be processed faster. However, the question remains whether inhibition is the only cause of faster target-processing or whether enhanced target-processing plays a role as well. In an ERP study by Luck (1995), it was hypothesized that multiple separable mechanisms of visual-spatial attention exert their influence during processes of attentional selection. Luck performed a cueing study, in which an attention-directing cue pointed to one of four possible target locations. Shortly after cue presentation, a small luminance target was presented immediately, followed by a pattern mask. The presented cue could be valid, invalid or neutral. EEG was measured during task performance and afterwards two early ERP components called ‘N1’ and ‘P1’ were singled out, both of which are thought to reflect attentional modulation in the visual domain (Mangun & Hillyard, 1991). The results showed that valid cues were accompanied by an increase in the amplitude of the N1 component compared to the neutral cue, whereas an invalid cue was accompanied by a decrease in P1 amplitude compared to the neutral cue. Furthermore, no increase in P1 amplitude was found on valid trials and no decrease in N1 amplitude was found on invalid trials. Mangun and Hillyard (1991) have shown that P1 and N1 modulations can occur independently of each other, suggesting that spatial cueing invokes two separate attentional processes, one that suppresses information at unattended locations as reflected by a decrease in P1 amplitude and the other that enhances information-processing at the attended location as reflected by a decrease in N1 amplitude. In the present study we found a benefit in target-processing by cueing a distractor location without cueing the target locations. These results are in accordance with the results found by Luck (1995) and Mangun and Hillyard (1991) showing that an inhibitory mechanism can function independently of a facilitatory mechanism.

In a classical cueing study, it is thought that regions in the visual cortex corresponding to the cued location become active resulting in response enhancement (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Heinze et al., 1994). This results in a bias in

the competition between the target and surrounding elements, leading to a faster and more thorough processing of the target. A similar but separable mechanism may be responsible for the inhibitory effects found in this study. Again, brain regions corresponding to the cued distractor location may become active, yet in a different way (possibly reflected by the reversed polarity compared with target-cueing), which leads to a diminished processing of information presented at the cued location.

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