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Does expectancy in Lateral Masking explain a target prevalence effect in Visual Search?

Bart Geelen
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Prof. dr. Lex Wertheim

Dr. Chris Paffen

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B.P. Geelen, A.H. Wertheim, C.L.E. Paffen, I.T.C. Hooge, and J.P. De Vries.

Dept of Pschychonomics, Utrecht University, The Netherlands

Abstract

The hypothesis tested in this paper was that manipulating target prevalence has an effect on lateral masking (measured as maximum gaze deviation from the target before it cannot anymore be perceived), which corresponds to what as has been reported in the literature on visual search, smaller maximum gaze deviations being associated with longer search times. The literature on visual search shows that low target prevalence causes longer search times in target present trials, but only at low levels of target prevalence. At higher target prevalence levels this is not the case. The present data suggest indeed a similar pattern of results in a lateral masking task: in target present arrays maximum gaze deviation appears to be reduced with lower target prevalence, but only at low target prevalence levels. In addition, in a control condition, in which subjects knew and perceived that a target was always present, larger maximum gaze deviations occurred. This supports the associated hypothesis that expectancy affects lateral masking. Taken together, these results are in line with the idea (Wertheim et al., 2006) that lateral masking could well be an important factor in visual search.

Introduction

Lateral masking is the phenomenon that the peripheral perception of a target is impaired when distractors are present in its adjacent surroundings. The impairment is more pronounced with distractors spaced close together and when the target with its adjacent distractors is positioned further away in the visual periphery (Bouma, 1970; Wertheim Hooge, Krikke & Johnson 2006; Wertheim, 2010). The strength of lateral masking is usually quantified by measuring how far one can divert one's gaze from the target without losing the ability to detect or identify it (method of maximum gaze deviation; Bouma, 1970). This standard method was used by Krikke, Wertheim and Johnson (2000) and Wertheim, et al. (2006) when providing evidence that lateral masking could be a very important, if not the main factor causing many of the well-known effects in visual search tasks, such as those traditionally attributed to higher level cognitive or attentional mechanisms. Using the same stimulus arrays, these authors observed a high correspondence between lateral masking scores and visual search times for target present search trials. This appeared to be the case for the well known effects of set size, disjunctions vs. conjunctions, display area, distractor density, the asymmetry effect (Q vs O's) and viewing distance. Generally they found that stronger lateral masking scores (i.e. smaller maximum gaze deviations) corresponded to longer search times and weaker lateral masking scores (i.e. larger maximum gaze deviations) corresponded to shorter search times (see also Wertheim, 2010).

Another factor known to affect visual search, but not investigated in this manner, is target prevalence: the percentage of target present trials across all trials (Wolfe, Horowitz & Kenner, 2005; Wolfe, Horowitz, van Wert, Kenner, Place & Kibbi, 2007; Wolfe & van Wert, 2010). In visual search, correct search times for target present trials increase slightly when target prevalence is reduced to less than 50% (Wolfe et al., 2007), but no effects occur at higher levels of target prevalence (Wolfe & van Wert, 2010). If the idea is correct that lateral masking is a main effect in visual search, as proposed by Wertheim, Hooge, Krikke & Johnson (2006), we should predict that lateral masking is affected by target prevalence in precisely that same way. If so, it would also mean that lateral masking can be affected by observer's expectations, as has already been suggested by Engel (1976) and van der Lubbe & Keuss (2001).

It should be mentioned here that the effect of target prevalence as reported to occur in target present search times (at low prevalence levels) is, although significant, actually rather small. The effect is much stronger with miss rates in target present search trials (Wolfe et al 2007). However, in the present lateral masking experiment only very few miss errors occurred. Neither could target absent lateral masking scores be used to test our hypothesis, because with such arrays there is no target masking at all. So we cannot test the present hypothesis with such scores. Thus our prediction becomes, that in a lateral masking task, target prevalence should have a small effect on maximum gaze deviation scores at low target prevalence levels. And this can only be tested with scores observed in the target present arrays.

This also implies that the method to be used in the present study must differ from that in the earlier Krikke et al. (2000) and Wertheim et al. (2006) experiments. They used the standard method of Bouma (1970) to measure lateral masking: moving the gaze away from the target as far as possible without loosing its perception. The point is that here we must manipulate target prevalence, i.e. the expectation of whether or not a target is present, and that implies inclusion of target absent trials. This makes the standard method to quantify lateral masking inappropriate, because with that method subjects always start by fixating a target.

However, the problem can be circumvented by having a subject move the gaze not away from the target, but towards it, starting at a point sufficiently far away from the target to prevent its peripheral perception, i.e. further away than maximum gaze deviation (see Wertheim, 2010 for such a suggestion). This way one can include a certain amount of target absent trials in a lateral masking task and thus manipulate target prevalence between conditions. Therefore, in the present study lateral masking was quantified by asking a subject to fixate a small fixation point, slowly moving towards the target until the target could be identified or until the subject decided there was no target. Given what is known about target prevalence in visual search with target present trials, we then expected maximum gaze deviation in target present trials to be slightly reduced with reduced target prevalence, but only at low levels of target prevalence. We also expected that the thus observed maximum gaze deviations are always smaller than when the standard method of Bouma (1970) is used, because with that method there is full knowledge of targets to be always present.

Method

Participants

Fourteen participants cooperated in this experiment, all students or graduates from Utrecht University, (age range 20 - 28 years, mean age = 23.1 years, *SD* = 2.1 years; 9women, 5 men). They were screened for dyslexia since dyslectics might be expected to have a-typical lateral masking (Bouma & Leigen, 1977). They all had normal or corrected to normal vision. Informed consent was obtained from the participants and they were either paid or received study credits for their participation.

Apparatus

Stimulus arrays were generated with Matlab and the Psychophysics toolbox (Brainard, 1997) on a MacIntosh computer. The target present arrays consisted of 1644 distractors and one target. The distractors consisted of the letter O. A target also consisted of the letter O, but with a small crossing line, making it resemble the letter Q rotated in either one of four different orientations (45, 135, 225 and 315 deg). The target absent arrays consisted of 1645 distractors. In all arrays the stimuli (diameter 0.7°) were arranged regularly in rows and columns (with 0.81° center to center distance), similar to the Wertheim et al (2006) study. The illumination of the lab was slightly darkened. Target and distractors were white (luminance 90.8 cd/m^2) presented on a grey background (luminance 45.8 cd/m^2). The arrays measured 38.3° by 29.4°, and were viewed from a chinrest at 59 cm distance from the screen. In every trial there was a red moving fixation point (14.8 cd/m^2, diameter 0.25°) moving horizontally either towards the target at 1.6°/ sec. from an extreme left or right starting position (experimental conditions), or away from the target (control condition).

In the experimental conditions targets could be presented in 4 slightly different positions around the center of the screen (in the center, 0.81° left off the center, and 0.81° or 1.62° right off the center) randomly and equally divided among trials. This prevented subjects from remembering the point of maximum eccentricity on the screen at consecutive trials. In all arrays the moving direction of the fixation point, the orientation of the stripe in the target and target position relative to the center of the screen, were equally balanced and randomly presented.

Conditions

Three target prevalence conditions were carried out. Each one included 64 target present trials. The number of target absent trials differed per condition. This yielded three prevalence conditions: 20% target present trials (64 target present trials, 256 target absent trials), 50% target present trials (64 target present trials, 64 target absent trials) and 80% target present trials (64 target present trials, 16 target absent trials). Finally there was a control condition in which the target was always present. Here lateral masking was measured with the standard method described by Bouman (1970), i.e. the target moved horizontally away from the target either to the left or to the right until maximum gaze deviation was reached. Every condition was presented as a block, apart from the 20% condition, which, given its large amount of trials, was split into two blocks.

To ensure a participant's ocular fixation on the moving fixation mark (with a smooth pursuit eye movement) thus avoiding "sneaky" saccades towards the target that would prematurely reveal the target to the subject, eye movements were recorded for each trial using the Eyelink toolbox (Cornelissen, Peters & Palmer, 2002). All eye traces were analyzed off line with a threshold consisting of twice the group average maximum gaze deviation for target present trials in the collective data. Trials with at least one horizontal saccade towards the target that passed this threshold were rejected and removed from analysis.

Procedure

To get familiar with the task, participants started with arrays of 10 trials until the experimenter judged them capable of performing the task correctly. They were told that it was very important to keep their eyes on the fixation point and prevent making “sneaky” eye movements towards the target. After this, the four conditions were offered randomly to the participants. At the start of each condition the participants were explicitly informed about target prevalence. Prior to each condition eye calibration was carried out.

An experimental trial began with the appearance of the fixation point that had to be fixated with the eyes. It was presented at 15.8° horizontally from the center of the screen. This was about 7° further away from the target than the average maximum gaze deviation as measured in a prior pilot study with two subjects (using the standard Bouman, 1970 method) and about 10° further then the average maximum gaze deviation as measured in the Wertheim et al. study (2006) with similar arrays.

When the participants pressed the spacebar on the keyboard of the computer, the screen was filled with a stimulus array and the fixation point began moving horizontally towards the target. An identification criterion was used, i.e. participants pressed the spacebar again as soon as they could identify peripherally the orientation of the stripe in the target while maintaining their gaze on the moving fixation point. They also pressed the spacebar as soon as they believed there to be no target. These points of maximum gaze deviation were registered by the computer.

At this second spacebar press, crosses appeared over all stimuli in the array (covering all four directions of the target stripe) thus eradicating any difference between target and distractors. This masked the position and nature of the target in iconic memory. After another space bar press the whole array was replaced by a text asking the participants to respond in which of the four directions the target stripe had been orientated. This was done by pressing one of four keys. A fifth key was used to indicate the belief that there had been no target.

Each block was followed with a short break of a couple of minutes. Participants were always asked whether they were ready to proceed or if they needed more time to pause. The time it took to complete a block depended on the condition. It took about 25, 20, 12 and 10 minutes to complete a block of the 20% target present trials condition, 50% target present trials condition, 80% target present trials condition and the standard condition, respectively.

Results

Four participants were unable to properly follow the ocular pursuit instructions in the majority of trials, making above threshold saccades toward the target in more than 50% of the trials. All data from these participants were removed from analysis. In the trials from the remaining ten participants (age 22 - 28 years, *M* age = 23.8 years, *SD* = 2.0 years; 6 women, 4 men) above threshold eye movements occurred as well. These were also removed from analysis. For the target present trials the percentage of trials removed was 22.0%, 23.0% and 20.6% in respectively the 20%, 50% and 80% target prevalence conditions. For the target absent trials these percentages were 21.4%, 24.4% and 18.1% respectively. In the remaining trials miss errors were very rare: 1.2%, 0.5% and 1.2% in the 20%, 50% and 80% target prevalence conditions. There was only one false alarm in the remaining target absent trials (in the 20% prevalence condition), and that trial was disregarded as well.

Thus the analysis in terms of maximum gaze eccentricity was made on a total of 1501 target present trials.

The means and standard deviations of these trials are listed in table 1, where as the means and standard deviations of target absent trials are listed in table 2.

Table 1. Summary of results for target present trials. Means and SDs refer to maximum gaze deviation between target and fixation point (deg.).

	20% target prevalence		50% target prevalence		80% target prevalence		control condition	
Subject	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	5.45	.88	5.89	.71	6.48	.75	10.3	.98
2	3.58	.94	4.08	.83	4.88	.69	10.35	1.36
3	4.74	1.46	4.81	1.31	4.66	1.32	9.44	.93
4	4.19	.97	5.22	1.18	5.33	1.18	7.42	1.12
5	3.11	.99	3.43	1.43	3.14	1.27	9.74	1.58
6	3.55	.80	3.64	.69	3.79	.77	7.67	1.05
7	5.08	.78	5.27	.85	5.02	.74	8.68	1.50
8	4.57	.86	4.90	.89	4.57	.92	8.31	.94
9	5.01	.96	3.84	.76	4.53	.97	9.37	1.16
10	6.42	1.19	7.24	1.36	8.14	1.32	11.81	2.31
Group mean	4.57		4.83		5.05		9.31	
Group mean SD	1.00		1.16		1.40		1.34	

Table 2. Summary of results for target absent trials. Means and SDs refer to maximum gaze deviation between the center of the screen and fixation point (deg.).

	20% target prevalence		50% target prevalence		80% target prevalence	
Subject	Mean	SD	Mean	SD	Mean	SD
1	5.86	2.32	5.70	2.32	5.60	2.9
2	3.53	1.81	4.64	1.81	4.71	1.89
3	10.52	2.65	10.71	1.97	9.90	1.97
4	5.65	2.44	7.88	1.75	5.58	1.79
5	3.39	2.18	7.34	2.48	3.72	2.00
6	5.21	1.95	5.06	1.81	4.45	1.71
7	8.26	2.3	7.14	1.85	5.20	2.04
8	7.62	1.43	7.28	1.61	6.45	.89
9	6.12	1.49	2.75	1.59	5.45	1.34
10	6.43	1.84	7.11	2.38	7.22	2.48
Group mean	6.26		6.56		5.83	
Group mean SD	2.14		2.16		1.74	

A repeated measures ANOVA with un-violated sphericity showed that the difference in lateral masking scores for target present trials between the 20%, 50% and 80% target prevalence conditions just failed to reach the 0.05 significance criterion ($F_{(2,18)} = 3.108$, $P = .069$). This was caused by one subject (nr 9). As can be seen from table 1, without this subject mean lateral masking scores in the 20% condition were all shorter than those in the 50% condition. Repeated measures ANOVA with a Greenhouse-Geisser correction for a-sphericity then showed a significant difference between the experimental conditions ($F_{(1.192, 9.534)} = 6.051$, $P = .031$). A pairwise comparison using a post hoc test (Bonferroni correction), revealed that when subject 9 was excluded from analysis, the 20% prevalence condition differed significantly from the 50% prevalence condition ($P = .014$).

For target absent trials, differences between the three target prevalence conditions were not significant ($F_{(2,18)} = 1.011$, $P = .384$).

A repeated measures ANOVA with a Greenhouse-Geisser correction for a-sphericity determined that lateral masking scores differed significantly between the experimental conditions and the control condition ($F_{(1.629, 14.929)} = 104.820$, $P < .0001$). A post hoc test (Bonferroni correction) revealed that, as expected, maximum gaze deviation was larger in the control condition than in either the 20% target prevalence condition ($P < .0001$), the 50% target prevalence condition ($P < .0001$), and the 80% target prevalence condition ($P < .0001$).

Discussion

For target present trials manipulating target prevalence resulted in the same trend on lateral masking scores as reported by Wolfe et al., (2007; 2010) with visual search times. With nine out of ten subjects low target prevalence (20%) reduced maximum gaze deviation scores relative to the 50% target prevalence condition, but not when this percentage was higher.

As mentioned earlier, the prevalence effect in visual search with target present trials has been reported (Wolfe et al., 2007) to be quite small and became smaller with larger set size (see their fig. 3; note also that the largest set size reported only contained 18 stimuli). Moreover, it was actually observed with only 2% target prevalence as compared to 50% target prevalence. We used much larger set sizes and 20% prevalence as compared to 50%, which may have reduced the magnitude of our effect even more.

Finally it should be noted that subject 9 showed data in the 50% condition that were questionable, because her average maximum deviation with the target absent trials was very small (2.75°) and as such deviated largely from all her other conditions, and also from all other subjects (see table 2). This suggests that in the 50% condition subject 9 continued to move the gaze closer to the center of the screen than necessary. Since this condition happened to also be the first condition presented to her in the whole experiment, it is possible that she initially used a very conservative criterion, as compared to the conditions presented later. Thus it is not surprising that our lateral masking trend just failed to reach significance due to only one deviating subject out of ten.

Wolfe et al., (2007; 2010) explained their prevalence effects in terms of signal detection, because it mostly affected miss error rates and search times in target-absent trials. However, in our case we cannot properly speak about lateral masking in target absent trials, because lateral masking of a target by distractors does not occur if there is no target. In our target absent trials participants could only be absolutely sure about the absence of a target by waiting for the fixation point to reach the middle of the screen (although subjects always gave their target-absent response earlier). This makes miss errors unlikely to occur (as was the case indeed) as compared to visual search tasks. Therefore in our case a signal detection approach is rather pointless.

However, the explanation of the prevalence effect as a criterion shift does seem applicable to our data. Indeed, it is plausible that when one expects only a few target present trials, one might become somewhat more careful, i.e. more conservative, and be less quick with identifying the target. That would lead to smaller maximum gaze deviations. However, the data suggest that this reasoning mainly applies when target prevalence is quite low.

As expected, with the target present trials maximum gaze deviation was significantly smaller for each of the experimental conditions as compared to the control condition.
This supports the assumption that expectation can affect lateral masking as indeed suggested in the literature (Engel, 1976; Van der Lubbe & Keuss, 2001). Thus, together with the findings of Krikke et al. (2000) and Wertheim et al. (2006) the present data lend support to the theoretical possibility that lateral masking is a more important mechanism in visual search than traditionally assumed.

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