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Preserved contextual cueing in realistic scenes in patients with age-related macular degeneration

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Abstract

Foveal vision loss has been shown to reduce efficient visual search guidance due to contextual cueing by incidentally learned contexts. However, previous studies used artificial (T among L-shape) search paradigms that prevent the memorization of a target in a semantically meaningful scene. Here, we investigated contextual cueing in real-life scenes that allow explicit memory of target locations in semantically rich scenes. In contrast to the contextual cueing deficits in artificial scenes, contextual cueing in patients with age-related macular degeneration (AMD) did not differ from age-matched normal-sighted controls. We discuss this in the context of visuospatial working memory demands for which both eye-movement control in the presence of central vision loss and for memory-guided search may compete. Memory-guided search in semantically rich scenes may depend less on visuospatial working memory than search in abstract displays, potentially explaining intact contextual cueing in the former but not the latter. In a practical sense, our findings may indicate that Patients with AMD are less deficient than expected after previous lab experiments. This shows the usefulness of realistic stimuli in experimental clinical research.

Introduction

When we enter an environment, eye movements can be guided by memory of the same or similar environments that we encountered in the past. When you think of your kitchen, you can explicitly tell where the refrigerator is and in which cupboard you will find a coffee mug. Similarly, when participants were asked to find a target in a realistic scene, search time was dramatically reduced when scenes - with the target placed at the same location - were repeated (Brockmole and Henderson, 2006). Unsurprisingly, participants were explicitly aware of the location of targets in the scenes when tested at the end of the experiment. However, search facilitation in repeated displays was also observed when the "scene" was a symbolic display, typically consisting of a T-shaped target among L-shaped distractors in a randomly generated configuration without any semantic meaning. Nevertheless, search time was reduced when these arbitrary distractor-target configurations were repeatedly presented. This contextual cueing effect, initially described by Chun and Jiang (1998) is an incidental learning effect. It occurs although participants are not told about the repetition of displays, and often in the absence of explicit recognition of the repeated spatial configuration. Although the implicit nature of contextual cueing has been debated (Vadillo, Konstantinidis, and Shanks, 2015), it has been repeatedly observed that only a fraction of displays can be explicitly recognized (Geyer, Shi, and Müller, 2010; Geyer et al., 2012). Furthermore, the amount of search facilitation, i.e. the reduction of search times in repeated displays, is typically not correlated with the confidence of recognizing a repeated display (Colagiuri and Livesey, 2016). Thus, contextual cueing in symbolic displays appears to be due to incidental learning processes that occur at least partially in the absence of explicit recognition, whereas contextual cueing in realistic scenes additionally draws on explicit memory.

In a previous study, we showed that incidental contextual cueing in symbolic displays was severely reduced in a group of patients with age-related macular degeneration (AMD;

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Geringswald et al., 2013). AMD is a degenerative disease leading to vision loss, particularly in the macula, i.e. affecting foveal vision. The loss of contextual cueing after foveal vision loss could be confirmed in a study with normal-sighted young participants in whom a foveal scotoma was simulated with gaze-contingent display methods (Geringswald, Baumgartner, and Pollmann, 2012) as well as in a further study with gaze-contingent central scotoma simulation (Geringswald, and Pollmann, 2015). In the latter study, however, when the simulated central scotoma was removed after a training session, allowing normal viewing of the search displays, the search time advantage for repeated displays (the same displays as in the central scotoma training phase) was immediately present. This pattern showed that search with a simulated central scotoma did not prevent the learning of repeated target-distractor patterns, but rather prevented the use of these memories for efficient search guidance. Once the scotoma simulation was removed, the configurations learned during central scotoma search could be used to guide search for the target when a display was repeated.

Thus, although incidental spatial configuration learning may occur in the presence of foveal vision loss, memory-guided search may suffer due to inefficient expression of learning. We know that the use of learned contexts for search guidance depends on visuospatial working memory. This has been shown by multiple studies using secondary working memory tasks to deplete working memory resources during search (Annac et al., 2013; Manginelli, Geringswald, and Pollmann, 2011; Manginelli et al., 2013; reviewed in Pollmann, 2019). These studies have shown that specifically the use of visuospatial working memory capacity by the secondary task reduced or abolished the search facilitation otherwise observed in repeated displays (Manginelli et al., 2012, 2013). In the case of foveal vision loss, the much more top-down controlled exploration of the environment, characterized by fewer saccades, longer dwell times, and larger saccade amplitudes puts high demands on visuospatial working memory, thereby preventing efficient search guidance by learned visuospatial contexts (Geringswald and Pollmann, 2015). However, while the visuospatial working

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memory demands of top-down controlled search may interfere with holding learned visuospatial patterns in working memory for search guidance, this may be different for explicitly remembered target locations in realistic displays (e.g. "the cup on the kitchen table"). The latter can be retrieved and held available during search very efficiently by semantic memory templates (Biederman, 1972; Vo and Wolfe, 2013), that do not compete with top-down controlled scene exploration for visuospatial working memory capacity. In support of this view, we recently reported that contextual cueing was intact for search in realistic displays with simulated gaze-contingent central or peripheral scotomata (Pollmann et al., 2020).

Therefore, in the present study, we hypothesized that the search in realistic scenes might enable Patients with AMD to show contextual cueing scores at a level comparable to those of age-matched controls with intact (best corrected) vision.

Materials and Methods

Participants: Twenty patients (eight males, all right-handed, mean age, 75.95 years; range, 55–85 years) with diagnosed age-related macular degeneration participated after providing informed consent. The study was approved by the local ethics review board of the Medical Faculty of OVGU (Nr. 76/08 of 14.06.2012 and 72/18 of 03.07.2018). Twelve patients were recruited and diagnosed at the Ophthalmic Department of the University Hospitals of the Otto-von-Guericke University, Magdeburg (OVGU), eight patients were recruited and diagnosed at the Eye Center am Johannisplatz (ECL) in Leipzig. Macular degeneration was determined based on an ophthalmic examination provided at the eye clinics. At OVGU, visual field defects were explored with standard static white-on-white perimetry (dynamic strategy; Goldmann size III; program: dG2; OCTOPUS Perimeter 101, Haag-Streit GmbH, Wedel, Germany). At ECL, the visual field was monitored by using the Amsler grid to detect the presence of metamorphopsia. With one exception, all patients were affected by AMD in both eyes, but the severity of the pathology varied across subjects (Table 1). Subjects with narrow iridocorneal angle, glaucoma, ocular trauma, eye surgery, (except cataract surgery), advanced cataract, diabetic retinopathy and other retinal diseases, high myopia (> 5 dpt), amblyopia, cerebral blood flow disorder, and stroke were excluded (see Table 1). Fourteen patients performed the experiment with monocular and 6 patients with binocular vision. From the 14 monocularly tested patients, 9 were tested with their worse eye and 5 with their better eye, because testing with the worse eye was not possible.

			Diagnoses		Acuity		Scotoma diameter (horizontal, vertical)	
Subject	Sex	Age (years)	RE	LE	RE	LE	RE	LE
S01	F	61	AMD(wet)	AMD (dry)	0.6	1.0	r	r
S02	F	80	AMD(wet)	/	0.1	0.8	r	r
S03	F	78	AMD(wet)	AMD(wet)	0.7	1.0	r	r
S04	F	79	AMD(wet)	AMD(wet)	0.3	0.05	r	r
S05	F	76	AMD(wet)	AMD(wet)	0.7	0.7	r	r
S06	F	55	AMD(wet)	AMD(wet)	0.8	0.8	r	r
S07	M	81	AMD (dry)	AMD (dry)	0.8	0.5/0.6	/	/
S08	M	74	AMD (dry)	AMD (dry)	0.04	0.5	/	/
S09	F	80	AMD (dry)	AMD (dry)	0.5	0.32	/	/
S10	F	84	AMD (dry)	AMD (dry)	1.0	0.8	/	/
S11	M	71	AMD (dry)	AMD (dry)	0.63	0.63	/	/
S12	F	78	AMD (dry)	AMD(wet)	0.8	0.4	/	/
S13	M	80	AMD (dry)	AMD (dry)	0.63	0.63	/	/
S14	F	75	AMD (dry)	AMD (dry)	0.03	0.8	c*	/
S15	M	79	AMD (dry)	AMD (dry)	0.63	0.63	/	/
S16	F	79	AMD (dry)	AMD (dry)	0.8	0.8	/	/
S17	M	80	AMD (dry)	AMD (dry)	0.32	0.08	1,1	/
S18	M	76	AMD (dry)	AMD (dry)	1.0	0.25	/	/
S19	F	72	AMD (dry)	AMD (dry)	0.7	1.0	10, 7	4,3
S20	M	80	AMD (dry)	AMD(wet)	1.0	0.08	12, 13	/

Table 1. Patient characteristics. Notes: RE, right eye; LE, left eye; AMD, age-related macular degeneration; –, no scotoma; r, relative scotoma; c*, central scotoma of unknown size. Patients S1-S6 were tested binocularly.

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In addition to the patients, we tested twenty controls binocularly (four males, all right-handed, mean age, 72.45 years; range, 66 – 79 years). Testing took place at Otto-von-Guericke University, Magdeburg. Controls' acuity was examined using the Freiburger Vision Test 3.9.9. (Bach M: Freiburg Vision Test. www.michaelbach.de/fract/index.html). All participants had normal or corrected to normal visual acuity (decimal visual acuity > 0.84).

Participants remained naive to the purpose of the research during the experiments. None of them had been tested in a similar study before. Immediately after the experiment individuals from both groups received a fixed reimbursement of Euro 20.- for the one-hour session.

Stimuli: The stimuli were presented and recorded by a Lenovo ThinkPad L420 (Linux operating system, version 8) using PsychoPy v1.82.01 Software (Pierce, 2009) under Python. The laptop was connected to a full color 24 inch HD LCD BenQ XL2410T presentation monitor. The monitor was 521 mm (1920 pixels) wide and 293 mm (1080 pixels) high, with a refresh rate of 120 Hz. Stimuli were presented at a distance of 80 cm in a quiet and dimly lit room. The stimuli were designed with Sweet Home 3D software (Sweet Home 3D, version 4.6, eTeks Paris, France. Available at http://www.sweethome3d.com). Twelve 3D-rendered illustrations of naturalistic scenes represented bath room, bed room, cinema room, game room, garage, nursery room, kitchen, library, living room, music room, office, studio (Figure 1).

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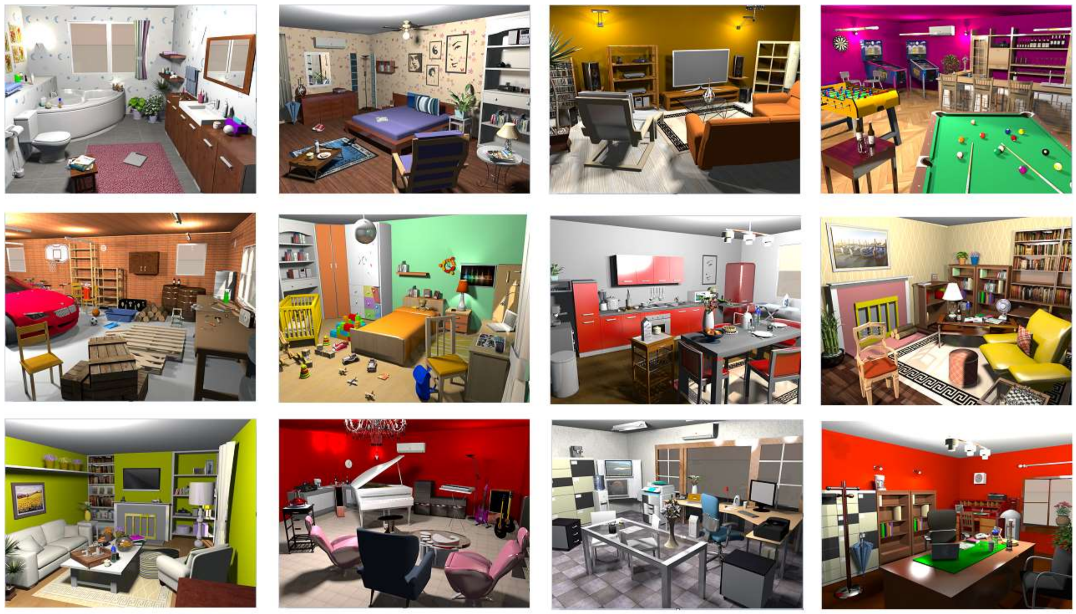

Figure 1. Interior scenes used in the experiment. The task was to search for the yellow mug (not present in the images above) and to indicate the left/right direction of the handle by an alternative forced choice response.

A yellow mug with a handle pointing either left or right constituted the visual search target and was presented in one of six equal-sized rectangular parts of the display (upper/lower, left/center/right). The mug could appear both in familiar positions as well as in unfamiliar positions in the rooms, but not in physically impossible places, e.g. up in the air. The orientation of the handle (left or right) was chosen randomly, balanced in each block.

Procedures: A trial began with the presentation of a central black fixation cross with a line length of 2.5° for 1000ms. After a blank screen of 500ms, the display was presented until participants indicated the direction of the mugs handle by an alternative button press response. After another blank screen for 500ms, the next trial began. Participants had to indicate the direction of the mug's handle by pressing the left or right mouse button. A 2000-Hz high-pitch tone provided positive, a 500-Hz low-pitch tone negative auditory feedback.

The visual search task consisted of six blocks, each block including 12 trials with 12 different rooms. In six displays (rooms) the mug's position was fixed across repetitions (repeated displays) whereas in the other six displays - the new displays - the mug's position varied randomly across the six rectangular sections. Target locations were chosen so that the probability of target presentation was the same across locations and for new and repeated displays.

Observers were not informed about scene repetitions. The sequence of the presented rooms was varied randomly across participants and the rooms that constituted the repeated displays were randomly drawn for each participant from the pool of all rooms. Figure 2 shows an example of a trial.

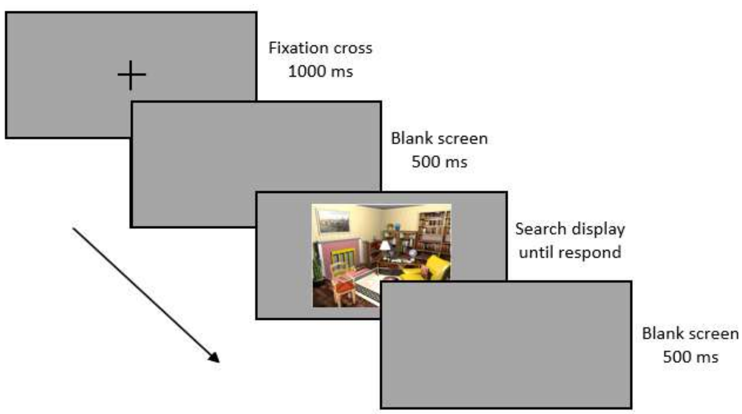

Figure 2. Example trial.

Recognition test: Subsequent to the experiment we ran an explicit recognition test in order to assess whether the repeated scenes were explicitly or implicitly remembered. The six previously repeated scene configurations were presented without the search target (mug). The participant´s task was to indicate the target´s position for each specific scene by pointing with the mouse cursor. Recognition accuracy was operationalized as the frequency of correct mouse cursor placements in the target display section (out of the six rectangular sections, see above).

Data analysis: All trials with incorrect responses (3% for patients, 1% for controls) and trials in which the search time exceeded the outlier threshold of ± 2 standard deviations from the mean (patients; 2.7% of repeated, 3.3% of new trials, controls; 2.4% in both trials groups) were excluded from the analysis. Mean search times (ST) were determined separately for repeated and new configurations for each subject and block. To increase statistical power, STs were aggregated to three epochs, each epoch containing two subsequent blocks. Next to STs, because of the different overall search times between patients and controls normalized contextual cueing effects [(ST(new) − ST(repeated))/ST(new)] were analyzed. Thus, positive values indicate a benefit for repeated configurations. When Mauchly's test indicated that the assumption of sphericity had been violated, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. For all statistical tests, the alpha level was set at 0.05.

Results

Search times: We first investigated potential effects of monocular vs. binocular viewing on ST in the patients. A repeated measures ANOVA with group (monocular, binocular) as between-subjects factor and configuration (repeated, new) and epoch (1-3) as within-subjects factors yielded neither a significant effect of group ($F(1,18) = .133$, $p = .72$, $\eta_p^2 = .007$) nor significant interactions with group (configuration x group: $F(1,18) = .021$, $p = .886$, $\eta_p^2 < .001$; epoch x group: $F(2,36) = .648$, $p = .53$, $\eta_p^2 = .035$; configuration x epoch x group: $F(2,36) = 1.218$, $p = .31$, $\eta_p^2 = .063$). Because of the absence of ocularity effects on visual search, we collapsed about ocularity in all further analyses to increase power.

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Averaged search times for patients and controls are shown in Figure 3. A repeated measures ANOVA with group (patients, controls) as between-subjects factor and configuration (repeated, new) and epoch (1-3) as within-subjects factors yielded a significant main effect of group ($F(1,38) = 11.410$, $p < .05$, $\eta_p^2 = .231$), yielded by overall faster search times of controls (1709 ms) compared to patients (3489 ms). The main effect of configuration was also significant ($F(1,38) = 7.361$, $p < .05$, $\eta_p^2 = .162$), indicating overall shorter search times in repeated displays (2465 ms) compared with novel displays (2733 ms), as expected due to contextual cueing. The significant main effect of epoch ($F(2,76) = 14.542$, $p < .05$, $\eta_p^2 = .277$) reflected decreasing search times over epochs, indicating general learning (3001 ms in epoch 1 to 2253 ms in epoch 3). Importantly, the interaction between epoch and configuration was significant ($F(2,76) = 3.547$, $p < .05$, $\eta_p^2 = .085$), indicating the development of contextual cueing over time (difference of novel - repeated display RT of -42.4 ms in the first epoch to 475 and 374 ms in the second and third epoch, respectively). Epoch interacted significantly with group ($F(2,76) = 5.696$, $p < .05$, $\eta_p^2 = .130$). Patients showed overall a much stronger decrease in search times over epochs than controls (1218 ms inprovement from the first to third epoch in patients versus 277 ms improvement in controls). The remaining interactions including the factor group were not significant, indicating that contextual cueing was comparable between patients and controls (configuration x group: $F(1,38) = .007$, $p = .934$, $\eta p^2 < .001$; configuration x epoch x group: $F(1,76) = 2.620$, $p = .079$, $\eta_p^2 = .065$).

The normalized contextual cueing scores that were analyzed because of the overall longer response times of the patients were analyzed with a repeated measures ANOVA with the within-subject factor epoch (1 - 3) and the between-subjects factor experimental group (patients, controls). Standardized cueing scores did not differ significantly between groups ($F(1,38) = 2.656$, $p = .111$, $\eta_p^2 = .065$). Moreover, neither the main effect of epoch ($F_{GG}(1.521, 57.817) = .948$, $p = .371$, $\eta_p^2 = .024$) nor the group x epoch interaction ($F(2,76) = .748$, $p = .477$, $\eta_p^2 = .019$) was significant. Thus, relative to the baseline differences, patients

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did not reduce their response times more than controls in the course of the experiment. Moreover, there was again no indication of a contextual cueing impairment in the patients.

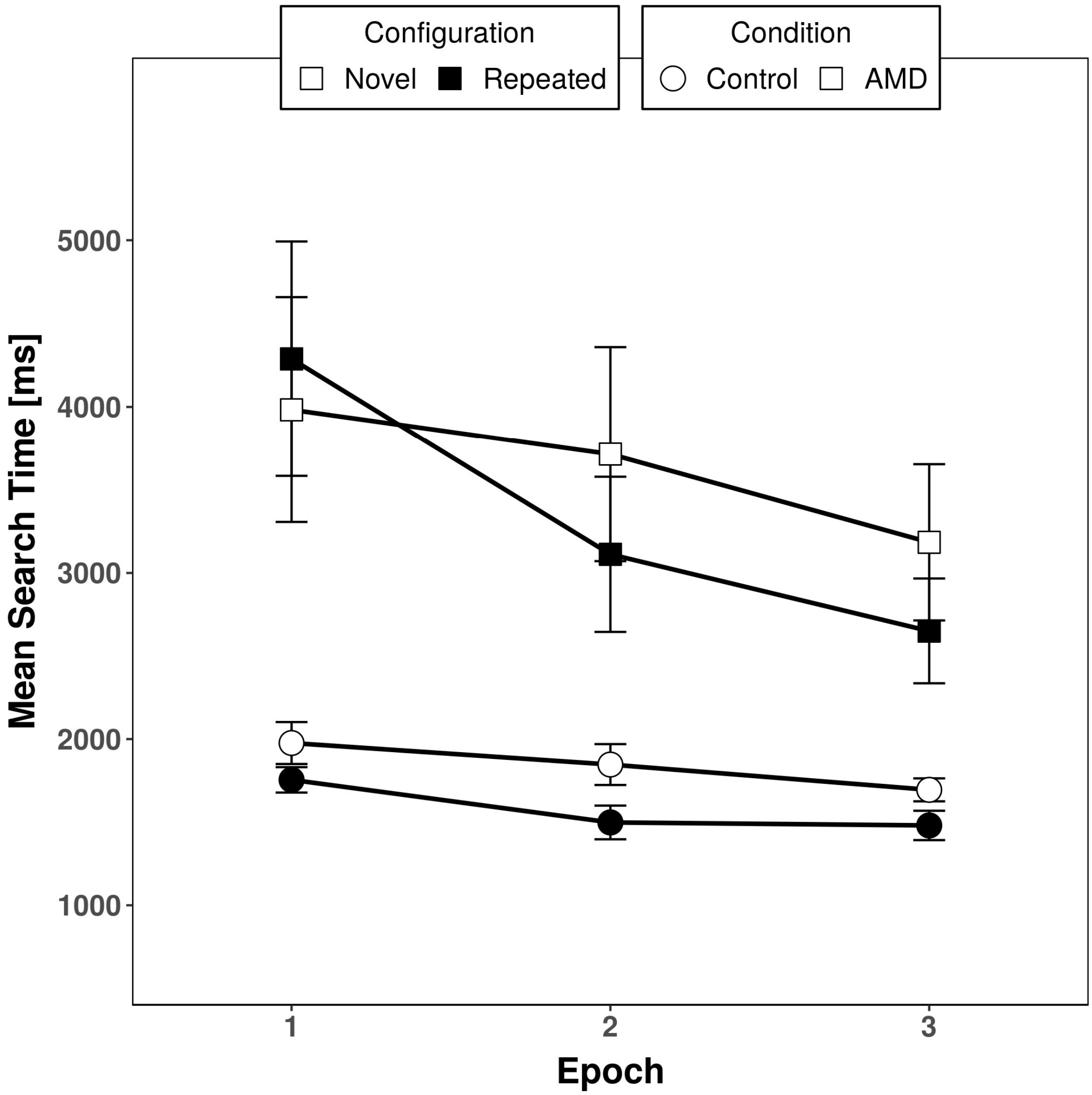

Figure 3. Averaged search times for controls (circles) and AMD patients (squares) as a function of repeated (filled symbols) and novel (open symbols) search displays. Error bars depict the standard error of the mean.

If contextual cueing is preserved in AMD patients when searching in real world scenes, contextual cueing scores should overall be unrelated to the degree of foveal vision

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impairment. To test this prediction, we correlated logMAR visual acuity as a measure of general visual performance and the normalized contextual cueing effect in repeated displays in the last epoch using Kendall's τ non-parametric rank order correlation (Figure 4). Only patients who had performed the experiment monocularly were considered for this analysis (n=14). LogMAR visual acuity of the tested eye did not correlate significantly with the size of contextual cueing ($\tau = -.069$, $p = .739$), implying that contextual cueing was also reliable in more severely impaired patients.

However, the absence of contextual cueing differences between patients and controls cannot be interpreted as positive evidence for equality of contextual cueing effects because it may be due to a lack of statistical power (Dienes, 2014). Therefore, to investigate the evidence for equal contextual cueing strength in both groups, we calculated a Bayes factor analysis on contextual cueing scores in the last epoch, where contextual cueing should be strongest. The analysis yielded a $BF_{01} = 2.989$, indicating that the null hypothesis of no difference in contextual cueing scores between patients and controls is almost three times as likely as the alternative hypothesis of a between-group difference in contextual cueing scores (Wagenmakers et al., 2018).

Accuracy. Accuracy is usually high in contextual cueing paradigms, because participants have no time limit (Jiang and Sisk, 2020). This was also observed in the present study, both for patients (monocular; mean 96 %, binocular; mean 97%) and controls (mean 99 %). Thus, whereas reaction times are the main variable of interest, accuracy was nevertheless analyzed to rule out potential speed-accuracy trade-offs.

A repeated measures ANOVA comparing accuracy with the between-subjects factor experimental group (control group, AMD monocular, AMD binocular) and the within-subjects factors configuration (novel, repeated) and epoch (1 -3) revealed no significant difference between groups ($F(2,37) = 3.223$, $p = .051$, $\eta_p^2=.148$). A significant main effect of configuration was observed ($F(1,37) = 5.713$, $p < .05$, $\eta_p^2=.134$), due to higher accuracy in

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repeated (98%) compared to new (96%) displays. The main effect of epoch was also significant, due to more incorrect responses in the first and fourth block ($F(2,74) = 3.42$, $p < .05$, $\eta_p^2 = .085$).

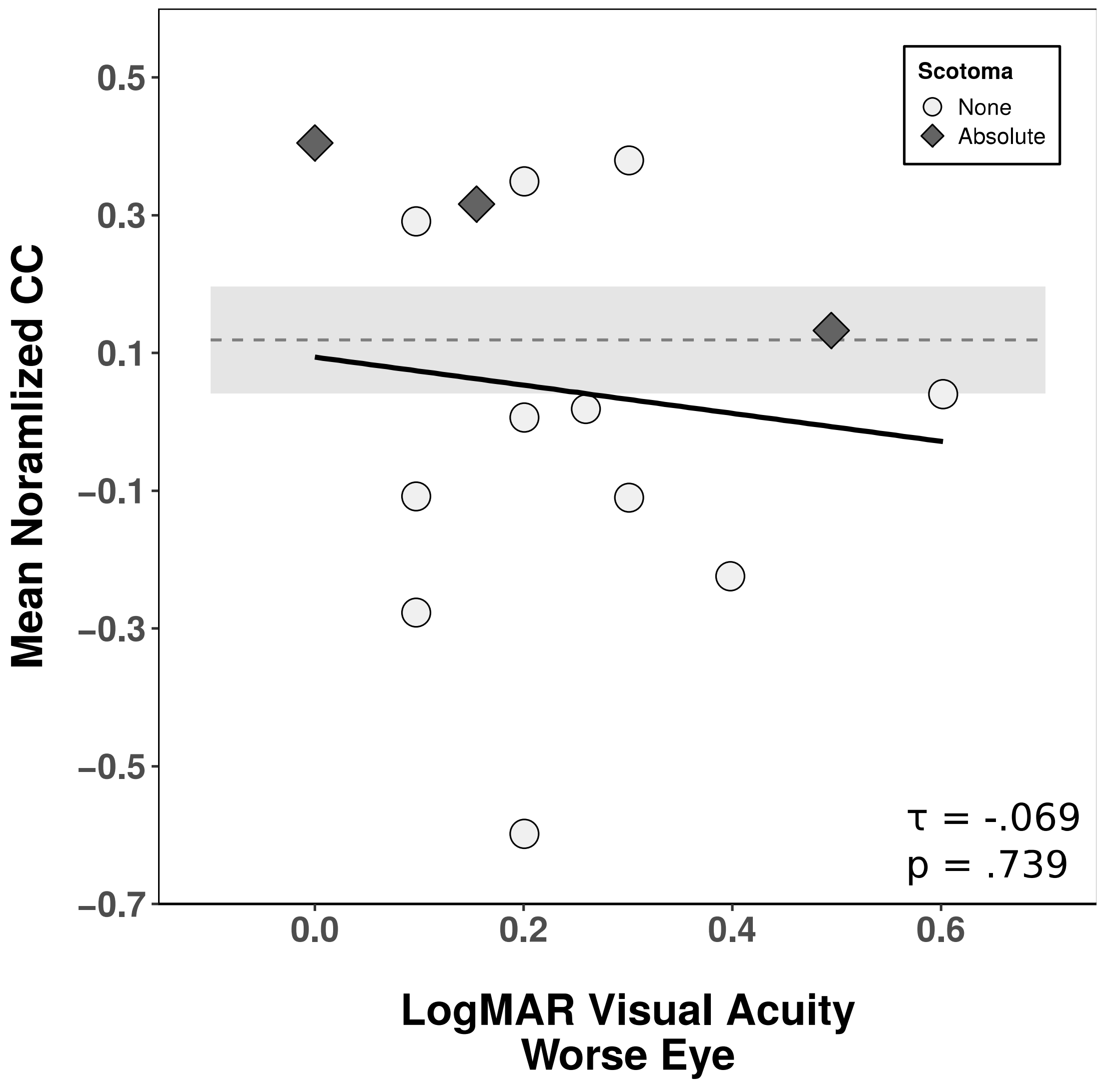

Figure 4. Relationship between the degree of foveal impairment in AMD (logMAR visual acuity worse eye) and normalized contextual cueing in search time in the last epoch in patients tested monocularly. Normalized contextual cueing was obtained by individually calculating the difference of mean reaction times between novel and repeated displays and standardizing this absolute difference by the mean reaction time of novel displays. Positive values indicate a benefit for repeated configurations. Rank correlations were quantified using

Kendall's τ. The solid line depicts the linear regression for the purpose of visualization. The dashed line represents the averaged mean normalized contextual cueing of controls and the shaded area the corresponding 95 % confidence intervals.

Recognition test. The experiment was followed by an explicit recognition test to address the question whether learning was implicit or explicit. For this purpose, the displays with repeated target location were presented again and the participants had to indicate the target sector (see methods). The average recognition accuracy in patients was 39.16%. To test whether the participants were able to recall the position of the target, we compared the accuracy obtained in the sample with the chance level of 16,6%, since in each trial the probability to select the right position was 1/6. Patients' accuracy was significantly above chance ($t(19)=5.107$, $p<0.001$), indicating that they recalled the repeated target locations. For the controls, accuracy was 58.33%. This, too, was significantly above chance ($t(19)=7.611$, $p<0.001$). Recognition accuracy was significantly increased for controls compared with patients ($t(19.167)=2.728$, $p=<0.01$).

Discussion

We investigated contextual cueing of visual search in repeated scenes in Patients with AMD. In previous studies with AMD-patients (Geringswald et al., 2013) as well as simulated central vision loss in normal-sighted observers (Geringswald, Baumgartner, and Pollmann, 2012; Geringswald, and Pollmann, 2015), impairment of contextual cueing was observed during search with foveal vision loss. In these studies, artificial displays were presented in which a T-shaped target had to be searched among L-shaped distractors. In the present study, we investigated if contextual cueing was preserved in Patients with AMD when searching in real

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world scenes. In line with previous work (Brockmole and Henderson, 2006), we found faster search times in displays with repeated target locations, indicating contextual cueing.

Although this search facilitation was numerically somewhat smaller in the patients than the controls, we observed no significant group x configuration interaction, which would have been indicative of group differences in the amount of contextual cueing.

Visual search in general - for new and repeated target locations alike - was much slower in the patient group, as was expected due to their impaired vision. While contextual cueing manifested itself in the faster search for targets at constant target locations, there was also an unspecific learning effect that led to faster search for both constant and variable target locations from epoch to epoch. This general learning effect was present in patients and controls alike. It may even have been somewhat stronger in the patients, as suggested by the group x epoch interaction in the age-matched patient sample (and the trend in the overall patient sample). This effect, however, could be attributed to their higher initial search times

We confirmed the central hypothesis of this paper that the clear contextual cueing deficit that we observed in previous work with AMD-patients (Geringswald et al., 2013) would be ameliorated for search in realistic displays. Our reasoning was that realistic displays would enable explicit memory of the target location in the form of a semantic template (e.g. The cup is on the kitchen table). In turn, this would resolve the competition between concurrent visuospatial working memory demands for top-down controlled exploration of the scene (e.g. navigating the fixation to the table) on the one hand and keeping a detailed visuospatial memory template active during search. In contrast, in symbolic displays, visuospatial working memory is needed both for keeping the contextual memory template active during search for comparison with the display and to navigate the display with eye movements concurrently (Geringswald and Pollmann, 2015). In keeping with this reasoning, we observed that patients and controls alike could explicitly remember the repeated target locations, unlike the AMD patients tested with symbolic displays in our previous contextual cueing study (Geringswald et al., 2013). Moreover, visual scene exploration was clearly impaired in the patients, indicated by their much longer search times. Thus, visuospatial working memory demands most likely were as high, if not higher, than for the patients with AMD of our previous study (Geringswald et al., 2013). This supports our view that patients did not use visuospatial working memory, but semantic memory to guide visual search in the present experiment.

Moreover, the present data show that the use of realistic stimuli may contribute to the question how well laboratory experiments can predict behavior and its limitations due to pathology in real life. The contextual cueing deficits that we observed in our previous work in AMD patients (Geringswald et al., 2013) may be compensated for in everyday situations by the use of semantic memory templates.

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