1040-5488/14/9108-1012/0 VOL. 91, NO. 8, PP. 1012–1020
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Space Representation in Age-Related Macular Degeneration

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ABSTRACT

Purpose. To investigate the effect of age-related macular degeneration (AMD) on memory for spatial representations in realistic environments.

Methods. Participants were 19 patients with AMD and 13 age-matched observers. In a short-term spatial memory task, observers were first presented with one view of a scene (the *prime view*), and their task was to change the viewpoint forward or backward to match the prime view. Memory performance was measured as the number of snapshots between the selected view and the prime view.

Results. When selecting a match to the prime view, both people with AMD and those in the control group showed systematic biases toward the middle view of the range of snapshots. People with AMD exhibited a stronger middle bias after presentation of close and far prime views while navigating accurately after a middle prime view. No relation was found between visual acuity, visual field defect, or lesion size and the memory performance.

Conclusions. Memory tasks using indoor scenes can be accomplished when central vision is impoverished, as with AMD. Stronger center bias for a scene location suggests that people with AMD rely more on their memory of a canonical view. (Optom Vis Sci 2014;91:1012–1020)

Key Words: low vision, macular degeneration, visual memory, space representation

Age-related macular degeneration (AMD), the leading cause of severe visual loss among the elderly in Western countries,[1,2] is a chronic, progressive macular disease that results in loss of central vision and significant functional impairment. Clinically AMD is characterized by atrophy of the retinal pigment epithelium, with (in the wet type) or without (in the dry type) choroidal neovascularization, which, in turn, produces a degeneration of the photoreceptors. Visual impairment has been shown to affect an individual's independence and physical, emotional, and social health.[3,4] Also, people with AMD have double the fall rate of healthy elderly people (16% vs. 8%).[5] It has been shown that people with AMD also exhibit difficulties in postural stability and mobility once the binocular central scotoma becomes larger than 10°.[6,7] Most studies showed that loss of contrast sensitivity and impaired visual field are the most important predictors of mobility performance.[6–14]

A number of previous studies have examined how people with AMD process visual scene information. A visual scene is commonly defined as a view of an environment composed of objects and surfaces organized in a meaningful way.[15] Previous studies in normally sighted young people[16–18] and in people with AMD[19] indicate that scene perception and scene recognition rely on global properties, which are distinct from local details. For example, the openness of the space or the degree of naturalness can be estimated from the scene as a whole (as opposed to a single-object detail), which is important when considering observers with AMD because most scene information often falls in the peripheral visual field during natural vision. In a previous work, we have shown that people with AMD are able to categorize scenes as natural/urban or indoor/outdoor with high accuracy (above 75% correct),[19] perform better with colored than with achromatic photographs of scenes,[20] and can more easily detect a target object when it is surrounded by its normal setting than when the same object appears on a disorganized background.[21] These results indicate that scene gist recognition can be accomplished with the low resolution of peripheral vision.

As a scene encompasses a large space in the natural environment, one must acquire information about its extent either by navigating or by moving the head and eyes. Effective navigation

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requires a person to retain knowledge of the final destination, the current location in an environment, and any obstacles that may lie along the way. With loss of central vision, the ability to obtain detailed information for navigation and memory of scene views is different. This may lead to systematic distortions in spatial representations resulting from central vision loss and may explain the orientation and mobility difficulties encountered by people with AMD. These difficulties would result, not only from a failure to detect objects, but also from a failure to accurately localize or remember specific locations within a larger environment.

What is the contribution of central and peripheral vision to spatial representations within a larger environment? It is known that central vision is responsible for resolving fine details while peripheral vision plays a role in spatial orientation and locomotion.[22] Few studies have explicitly tested the influence of central and peripheral fields on the nature of spatial representations during online scene perception. Turano and Schuchard[23] had participants with normal vision, peripheral vision loss, or central vision loss make relative distance judgments while sitting in one location. The results showed that participants with either type of field loss exhibited higher levels of spatial localization errors than normally sighted participants. However, it was not possible to determine whether there were any systematic trends in the errors exhibited by participants with visual field loss.[23] Fortenbaugh et al.[24] demonstrated that information in the peripheral visual field provides important global spatial information used in constructing a representation of the larger spatial environment. Simulated peripheral field loss in normally sighted participants, while they walked in a virtual environment, led to systematic distortions in remembered target locations. In general, peripheral vision loss from retinitis pigmentosa was found to be associated with distortions in spatial representations, which increased with decreasing field of view.[25] These results indicate the importance of peripheral information for space representation by using paradigms that limit vision to the central field.

In the present study, we assess the spatial representations of patients who only have peripheral information because of central vision loss from macular degeneration. Specifically, we examine how accurately observers can navigate to a remembered location in a realistic indoor scene and we investigate the relationship between performance and clinical data. To simulate an observer walking forward or backward in the scene, we created a series of 25 images for each indoor scene ranging from a distant view of the scene to a close up view. Participants were presented with a view from one location in the space for 500 ms (the *prime view*). Then, a navigation procedure from a *starting view* was simulated by having the observer press keys to move forward or backward in the scene until they thought that they were located in the same place in the environment as they saw in the *prime view*. Performance was measured by the number of errors of steps (backward or forward) different from the final location to the *prime view*.

METHODS

Participants

People with AMD

People with AMD with foveal involvement were recruited. Inclusion and exclusion criteria are summarized in Table 1. Patients were tested monocularly. In cases of bilateral AMD, we considered the eye with the best corrected visual acuity. If both eyes had equal acuity, one eye was randomly selected.

Best corrected visual acuity (BCVA) was determined using Early Treatment Diabetic Retinopathy Study charts at a distance of 4 m. Fundus autofluorescence was performed in atrophic AMD and fluorescein angiography in neovascular AMD, using a Scanning Laser Ophthalmoscope (Heidelberg Retina Angiograph, HRA2; Heidelberg Engineering, Dossenheim, Germany).[26,27] The area of geographic atrophy (mm^2) was measured by outlining dark atrophic areas using image analysis software (Heidelberg Eye Explorer). The entire complex component (choroidal neovascularization, elevated blocked fluorescence, and thick blood) is considered to constitute the neovascular lesion. The area of the choroidal neovascular lesion[28] (mm^2) was measured from digital angiograms by outlining the lesion, with the same software.

The demographic details and clinical data of AMD participants are summarized in Tables 2 and 3. Nineteen patients with AMD were included in the study. They ranged in age from 59 to 91 years. The logMAR visual acuity was 0.94 ± 0.45 (approximate Snellen visual acuity 20/150). The size of the lesion was variable, ranging from 1.46 to 52.7 mm^2 with a mean size of 10.6 ± 12 mm^2. In dry AMD, the mean surface of atrophia was 16.2 mm^2, and in neovascular AMD, the mean surface of the lesion was 7.3 mm^2. The mean greatest diameter of the lesion in neovascular AMD was 3.04 mm, corresponding to a central scotoma of approximately 10° of visual angle.[29]

TABLE 1.
Inclusion and exclusion criteria for AMD participants

Inclusion criteria	Willing to give informed consent
	Clinical diagnosis of atrophic AMD or neovascular AMD well defined with subfoveal involvement confirmed by fluorescein angiography
	Best corrected visual acuity between 20/40 and 20/400 in the eye to be studied
	Refraction between +3D and −3D
Exclusion criteria	History of any neurological or psychiatric disease
	History of ophthalmologic disease other than AMD that might compromise visual acuity or peripheral vision (amblyopic, uncontrolled glaucoma, optic neuropathy, diabetic retinopathy, uveitis)
	Unable to communicate (deafness)
	Treated with medication that might compromise concentration (benzodiazepine, narcoleptics)
	Mental deterioration with MMSE score <24/30

TABLE 2.
Demographic and clinical data of the studied populations

AMD participants	n = 19
Age (years), mean ± SD (range)	79 ± 8 (59–91)
Sex (M/F)	8/11
MMSE, mean (range)	28 (26–30)
Mean logMAR VA	0.94 ± 0.47
Lesion size (mm^2), mean ± SD	12.8 ± 14
Loss of sensitivity (dB/deg^2), mean ± SD	743 ± 435
Elderly controls	n = 13
Age, mean (range)	73 (59–81)
Sex (M/F)	6/7
Mean logMAR VA	0
MMSE, mean (range)	29.5 (28–30)

AMD, age-related macular degeneration; F, female; M, male; MMSE, Mini Mental State Examination; SD, standard deviation; VA, visual acuity.

Central and peripheral visual fields were assessed using the Mix 30 program of the Vision Monitor (Metrovision, Lille, France). This program combines the evaluation of the peripheral visual field with the kinetic perimetry to the evaluation of the central field with the FAST (Fiber Adapted Static Testing) perimetry (94 points), as previously described (more technical details can be found at http://metrovision.fr).[19] Central and peripheral visual fields were available in 17 of 19 patients. In 2 patients (patients 14 and 15), visual field measurement was not possible because of fatigue, poor vision (20/400), or multiple loss of fixation during the test. No patient exhibited constriction of the peripheral isopter. FAST-30 perimetry revealed a central scotoma in all patients, which included absolute (deficit >20 dB) and/or relative scotoma (loss of sensitivity) in 12 of 17 eyes. The scotoma was recorded eccentrically in 5 patients.[30] The absolute scotoma size varied from 5° to 30° of eccentricity. The volume of sensitivity losses (dB/deg^2), computed by Vision Monitor software, was used to measure visual field deficit.

Controls

Age-Matched Participants

Thirteen age-matched participants (mean age = 73 years; six males and seven females) with no history of ophthalmologic disease were included. Age-matched control participants were either a relative of participants with AMD or patients who had successful cataract surgery with noncorrected visual acuity ranging from 20/25 to 20/20.[31] They were tested monocularly on their preferred eye. A test of cognitive deterioration (the Mini Mental State Examination [MMSE]) was administered to both groups of participants. The mean MMSE score for healthy normally sighted controls was 29.5/30. It was lower for patients with AMD, varying between 26 and 30/30. The lower score for patients was because of items requiring good vision (e.g., to copy a figure, to name objects, to read, and to write a sentence). People with AMD were not impaired in items of the MMSE involving language and memory.

Both participants with AMD and controls were recruited in the ophthalmology department of the hospital Saint Vincent de Paul, Lille, France. The study was approved by the ethical committee (CPP Nord-Ouest IV), in accordance with the tenets of the Declaration of Hensinski. Written informed consent was obtained from all participants.

Experiment

Apparatus

Participants were seated 40 in. away from a 30-in. monitor (Dell) for the task. All stimuli were presented to fill the entire screen and subtended 65° visual angle. Stimuli were presented using custom-developed software, designed by one of the authors (P.D.) in C++. Participants were tested in a dimly illuminated room. They were told not to move their body and their head during the experiment. Eye movements were possible, allowing visual exploration. A box containing two response keys was connected to the computer. The participant's head was not fixed.

Stimuli

Twelve different indoor spaces were constructed using DataBecker 3d Home software® (e.g., kitchens, bedrooms, living rooms, etc.). For each room, a series of 25 images was taken, starting from the front of the room (''close view''; step 1) and continuing backward for 25 steps to the back of the room (''far view''; step 25). Each image series formed a virtual path through the room through magnified and minified views of the scenes.

Spatial Memory Task

On each trial, 1 of the 25 snapshots of a scene (a *prime view*) was displayed for 500 ms. This *prime view* could be a close view (steps 5 to 7), a middle view (steps 12 to 14), or a far view (steps 19 to 21). After a 1-second blank delay, the observer was placed in the same room, with a *starting view*, either at the front (steps 1 to 2) or back (steps 24 to 25). Observers used the up and down response keys to navigate forward and backward, respectively, until they thought that they were located at the same place in the environment as they saw in the *prime view* (see Fig. 1). When observers thought that they reached the estimated location of the *prime view*, they verbally signaled to the experimenter, who then pressed a key to validate the response. The structure of the trial and an example of the image series are shown in Figs. 1 and 2.

Each of the 12 scenes was tested in six conditions, with three different prime views (*Close/Middle/Far*) and two starting positions (*Start Back/Start Front*), yielding 72 total trials in the experiment. These trials were presented in a random order across subjects. People with AMD and age-matched controls were tested in one session of 72 trials. Performance was quantified by the number of steps from the final location (response) to the *prime view*, with the convention that positive errors indicate that observers are farther away from the prime view and negative errors indicate that observers were closer to the front of the scene than the prime view. The experiment started with a practice session of 5 trials to ensure observers understood the experiment. In the practice session, the prime view scene was presented for 3000 ms.

Statistical Analysis

To assess overall performance, a $2 \times 3 \times 2$ mixed analysis of variance (ANOVA) was conducted with group as a between-subject

TABLE 3.
Individual clinical data and performance of the navigation task for people with AMD and age-matched controls

No./sex/ age (years)	AMD type	MMSE	Visual acuity (logMAR)	Lesion size (mm^2)	Loss of sensitivity (dB/deg^2)	Start front–close prime view	Start front–middle prime view	Start front–far prime view	Start back–close prime view	Start back–middle prime view	Start back–far prime view
AMD											
1/F/76	Wet	29	1	1.99	663	0.58	−0.11	−3.9	2.79	−0.6	−1.44
2/M/80	Wet	28	0.9	7.88	663	11.95	7.86	−1.56	10.05	6.13	1.33
3/M/59	Wet	30	0.6	1.46	253	5.97	−1	−1.1	3.54	0.27	−3.06
4/F/88	Wet	26	0.6	6.94	533	−1.375	−4.66	−8.4	10.86	5.9	0.25
5/M/75	Wet	30	1.3	3.55	533	−0.1	−1.7	−8.3	−0.46	1.3	−0.85
6/M/62	Wet	30	1.3	3.59	151	1.91	0.91	−1.4	3.91	1.46	0.68
7/M/80	Wet	29	0.6	12	733	−0.39	−2.5	−4.05	0.58	−0.43	−0.55
8/M/73	Wet	29	0.6	4.72	891	4.96	−3.2	−9.4	13.2	7.6	0.19
9/M/89	Wet	29	0.8	14.09	522	−0.79	−4.325	−9.75	10.06	3.93	−2.36
10/M/79	Wet	26	1	5.38	1334	0.56	−7.48	−12.94	14.6	8.5	1.5
11/F/77	Wet	29	0.8	23	857	0.89	0.23	3.55	1.2	−1.8	−0.5
12/F/83	Wet	30	0.4	3.53	91	1.23	−1.45	−8.47	3.01	1.8	1.88
13/F/77	Dry	26	1	2.59	440	0.21	−0.66	−1.25	1.22	−1	−2.25
14/F/91	Dry	27	2	8.26	ND	1.145	−1.1	−5.6	2.54	−0.27	−2
15/F/84	Dry	27	2	52.72	ND	2.19	−2.03	−2.85	4.6	0.32	−2.19
16/F/82	Dry	27	1.3	15.97	1492	−0.75	−1.29	−6.13	6.97	2.32	0.16
17/F/87	Dry	27	1	26.7	1296	1.68	0.2	−2.47	3.3	0.15	0.06
18/F/82	Dry	30	0.4	3	300	0.26	−4.05	−9.75	4.7	1.75	0.91
19/F/82	Dry	30	0.5	4.3	480	−1.81	−5.02	−10	9.37	6	1.21
Controls											
1/F/76	N/A	30	0			−0.33	−2.18	−2.68	1.26	−1.08	−1.52
2/M/63	N/A	30	0			0.525	−0.25	−2.45	0.25	0.4	0.22
3/F/81	N/A	29	0			2.35	−1.16	−3.85	−6.16	0.4	−2.69
4/F/76	N/A	30	0			−0.58	−0.66	−0.27	−0.45	0.7	−0.56
5/F/65	N/A	30	0			−1.4	−0.94	−3.46	2.85	−0.86	−1.58
6/M/77	N/A	29	0			0.71	−1.16	−1.53	−0.79	−0.68	−1.41
7/F/75	N/A	30	0			0.33	0.44	−0.97	4.94	0.45	−0.13
8/M/81	N/A	30	0			−0.4	0.05	−5.7	0.38	−1.93	−2.78
9/F/77	N/A	28	0.1			1.05	0.47	−1.76	3.91	1.53	−0.51
10/M/80	N/A	30	0			−0.45	−0.075	−1.66	2.7	1.9	0.38
11/M/59	N/A	30	0			−1.33	−4.86	−6.75	3.06	1.23	−0.6
12/F/80	N/A	26	0			4.8	−0.95	−10.05	16	6.26	−0.1
13/M/62	N/A	30	0			−0.375	−2.58	−4.15	4.875	1.6	0.41

Performance of virtual navigation is explained in step errors (number of steps between the prime view and the response), in different conditions of navigation from the starting view to the prime view that the observer had to reach. Positive errors indicate that observers navigated to a scene that was farther away than the prime scene, whereas negative errors indicate that observers navigated to a scene that was closer than the prime scene.

AMD, age-related macular degeneration; F, female; M, male; MMSE, Mini Mental State Examination; ND, not done; N/A, not applicable.

factor (patients with AMD vs. age-matched controls), prime view as a within-subject factor (close, middle, or far prime view), and starting position (front/back) as a within-subject factor. Correlations between performance and logMAR visual acuity, lesion size area, and the loss of sensitivity on visual field testing were performed by using Pearson correlation and the matching significance of the correlation (p).

Statistical significance is reported at $p < 0.05$. All data were analyzed using the software Statistica (Version 8; StatSoft, France).

RESULTS

Overall Performance

Performance for age-matched controls and people with AMD is shown in Fig. 3. There was a significant main effect of the prime view ($F_{2,56} = 53.4$, $p < 0.001$). After seeing a middle prime view, observers tended to accurately navigate to that position. However, after seeing a close prime view, all observers tended to navigate to a scene that was slightly farther than the prime scene (positive error steps). Conversely, after seeing a far prime view, observers tended to navigate to a position slightly closer that the scene (negative error steps).

Effect of the Starting View

Performance was also significantly affected by where the observer started in the scene ($F_{1,56} = 21.9$, $p < 0.001$). Both controls and patients underestimated the walking distance: when starting to navigate from the back of the room walking forward, observers tended to not walk close enough. Similarly, when starting at the

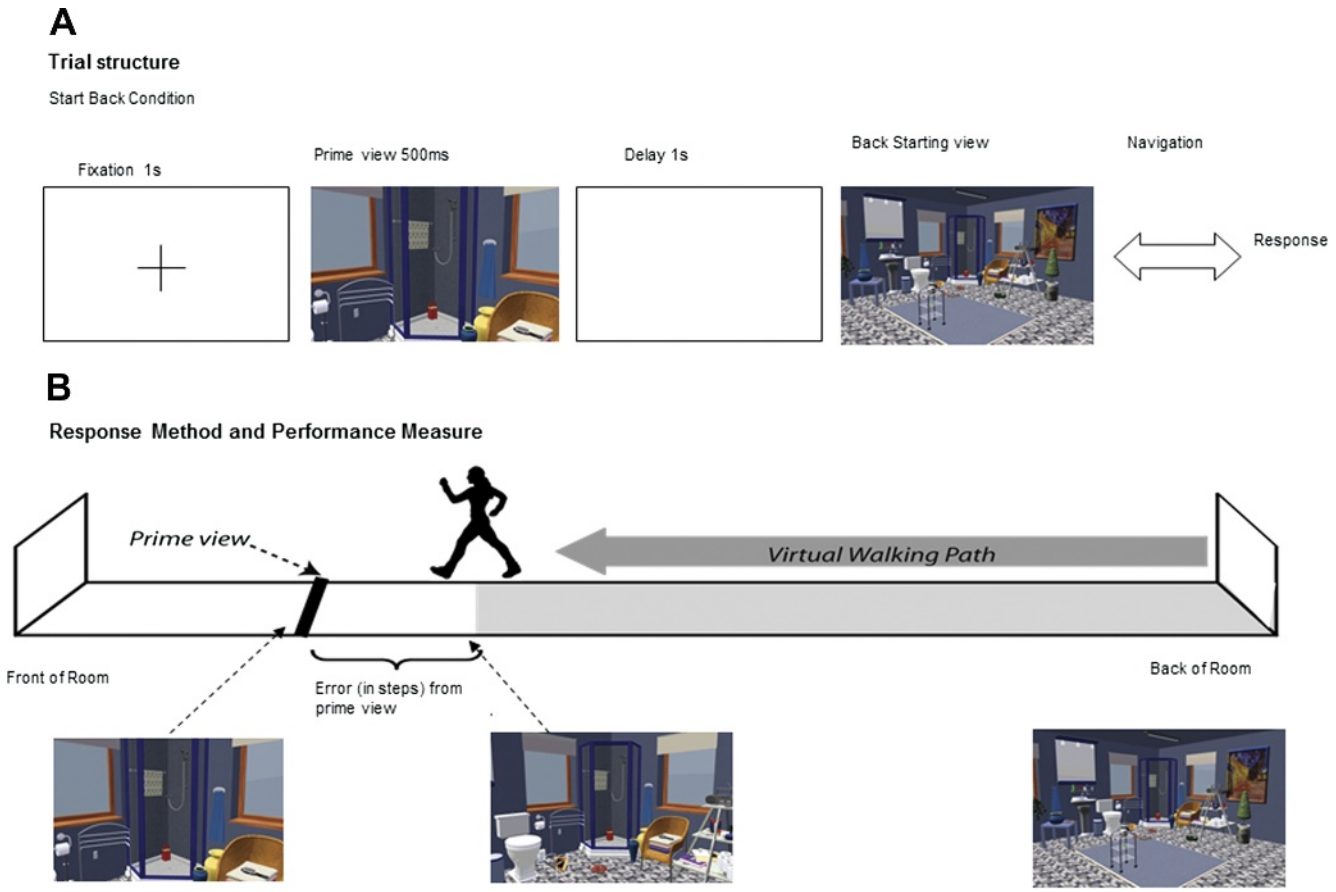

FIGURE 1.

A, Trial structure. In each trial, observers were presented with a prime view for 500 ms, which could be either a close (steps 5 to 7), middle (steps 12 to 14), or far view (steps 19 to 21) of a room. After a 1-second delay, observers were placed into the room at either the front (start front; steps 1 to 2) or the back (start back; steps 24 to 25) and had to navigate using the up and down response keys to arrive at the prime view. B, Response method and performance measure. In this example, a prime close view (step 5) was presented, and then the observer was placed at the back of the room (black starting view; step 25). Observer had to follow a virtual walking path forward to reach the prime view (response). The performance was measured in terms of the number of steps between the prime view and the final location (response). Positive errors indicate that observers navigated to a scene that was farther away than the prime scene, whereas negative errors indicate that observers navigated to a scene that was closer than the prime scene. In this example, the response view (step 11) reflects a +6 error score.

front of the room, observers tended not to move far enough back. The magnitude of this hysteresis effect was not significantly different for the close, middle, or far prime views ($F_{2,56}$ = 1.1, ns).

Effect of Groups

Comparing patients and controls, there was a significant effect by *prime view* interaction ($F_{2,89}$ =12.8, p = 0.05) resulting from people with AMD exhibiting larger errors for the close and far scenes than controls (close: control = 1.45 steps, patients = 3.53 steps; far: control = −2.15 steps, patients = −2.92 steps) and being as accurate for the middle prime view scenes (middle: control = −0.15 steps, patients = 0.32 steps). In other words, both groups showed a bias to navigate to a more central location in the room, but patients with AMD had an even stronger center bias. The effect of starting position on performance was not different between patients and controls ($F_{1,56}$ = 2.9, p = 0.102). Furthermore, there was no main effect of group on performance ($F_{1,89}$ = 1.01, p = 0.32), and there was no three-way interaction between group, prime view, and starting position ($F_{2,56}$ = 1.8, p = 0.168).

Correlation Analysis

There was a significant relationship between visual acuity and lesion size (r = 0.49, p < 0.05, df = 17) and between lesion size and volume of sensitivity loss (r = 0.63, p < 0.01, df = 17). No correlation was found between individual performance score and any of the clinical measurements (visual acuity, lesion size, and visual field testing).

DISCUSSION

The present study demonstrates that people with AMD and age-matched normally sighted controls exhibit two systematic behavioral effects in this spatial memory task. First, both groups show a hysteresis effect based on their starting position in the scene: observers tended to stop too soon, both when starting from the front or the back of the room. Second, both groups showed systematic biases in the remembered location of the prime view, navigating to a more central location in the scene. These results suggest distance underestimation in patients with AMD and in the

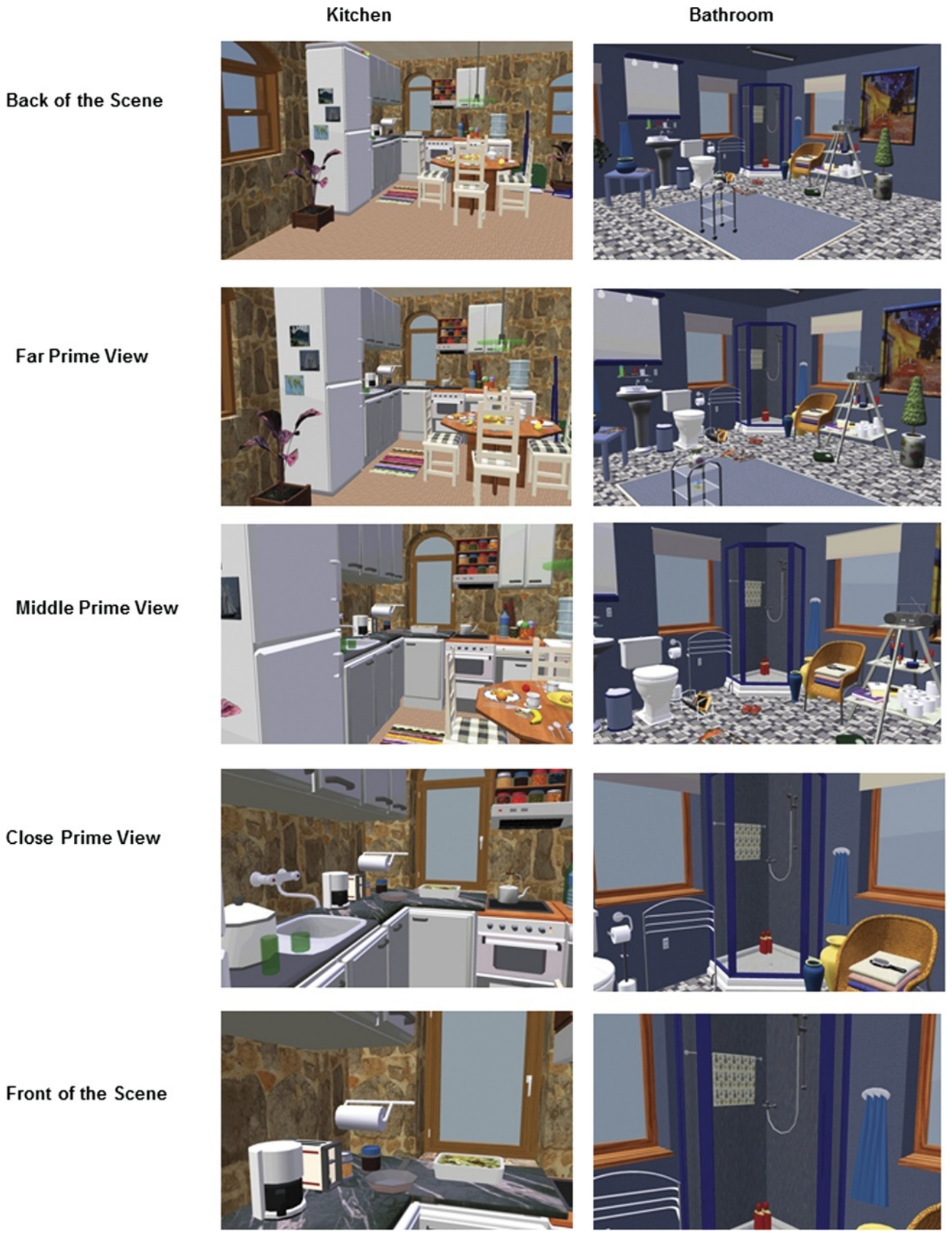

FIGURE 2.

Series of images of familiar indoor scenes presented as starting views and prime views. Two example scene environments are shown in the two columns. The farthest view is the starting back view, corresponding to step 25 (top row) and the closest view is the starting front view, corresponding to step 1 (bottom row). The three prime views are depicted in between, showing the far prime view (step 20), the middle prime view (step 13), and the close prime view (step 6).

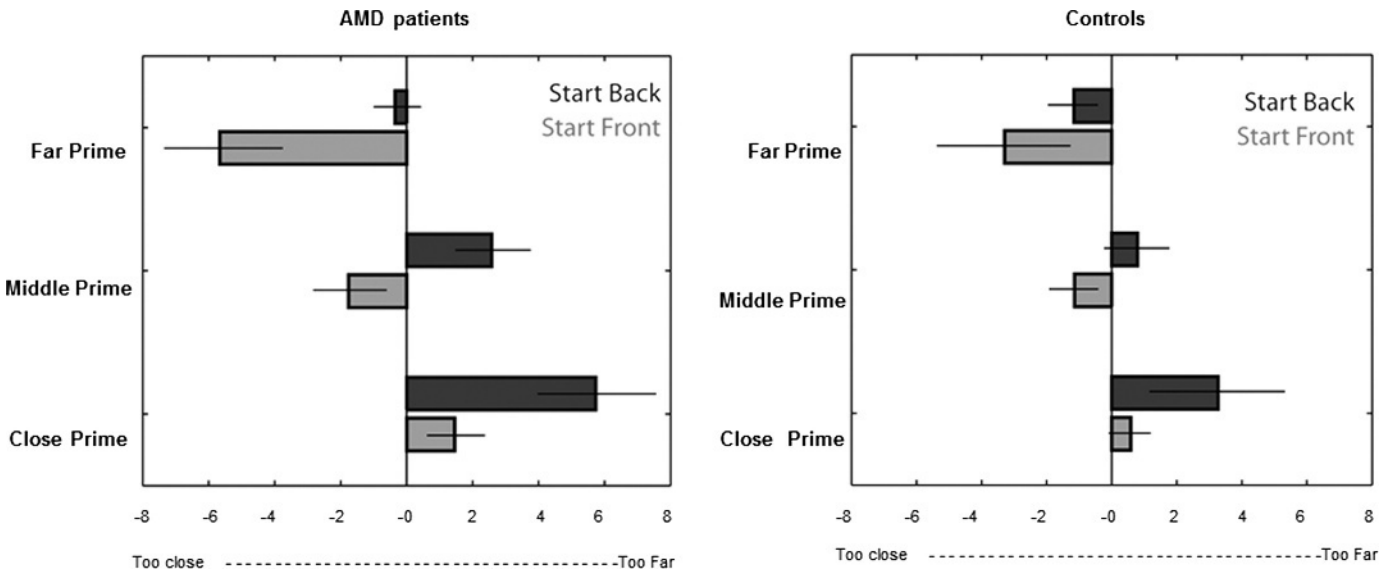

FIGURE 3.

Overall performance results for people with AMD (left) and controls (right). Memory performance for the far, middle, and close prime views is shown (*y* axis), both when navigating from the front (light gray) and back (dark gray). If people navigated perfectly to the prime view, the error would be 0. Negative numbers indicate that people navigated to a closer view than the primed scene; positive numbers indicate that people navigated to a farther view than the primed scene. Error bars represent within-subject 95% confidence intervals. People with AMD showed larger errors for the close and far scenes than controls, with a stronger center bias: they tended to navigate farther back after viewing a close prime view and tended to navigate to a position closer than the scene after viewing a far prime view.

control group. Tarita-Nistor et al.[32] showed that both elderly control group and patients with AMD underestimated distance in all four directions, and the direction of bias was not predicted by the preferred retinal location. Patients with AMD also had larger bias than the control group in a spatial judgment task.

The hysteresis effect might have been driven by some form of interference (i.e., when there are many intervening views, the memory of the prime view is harder to retrieve), but there was no interaction involving the hysteresis effect between people with AMD and those in the control group. In contrast, there was an interaction between patients and control group in the center bias estimates. Indeed, people with AMD navigated accurately after presentation of a middle view but exhibited stronger center bias after presentation of a close or a far prime view compared to the control group.

The center bias result can be considered within the context of the *boundary extension* effect in which observers tend to remember a greater expanse of a scene that was shown in a photograph.[33,34] Interpreting this phenomenon in a three-dimensional context suggests that, when observers remember a particular view, they "step back" in their memory. We find this effect in our navigation paradigm because observers presented with a close view of a scene tend to navigate to a location that is farther away. However, when presented with a far view, observers tend to remember a scene that is few steps forward. Why might observers show a center bias?

Patients and controls likely differed in their encoding of the scene (the prime view). Two strategies are efficient in performing the task: either memorizing the size of a central object in the prime view and selecting the same size in the following views or memorizing the objects or part of the objects appearing at the edges of the scene in peripheral vision and finding the same objects or part of objects in the following views (e.g., in Fig. 2, the window on the left edge in the kitchen). Because of their degraded central vision, it is likely that people with AMD relied more on the objects appearing at edges the of their peripheral vision. Although patients and controls did not differ significantly in their MMSE scores, there is still a possibility that they differed in their maintenance and match-to-memory processes. This warrants a further study.

Another framework in which to interpret these results is to consider scene perception as an active process, in which images are combined with memory and experience to create an internal reconstruction of the visual world. Existing scene schemas of living rooms, kitchens, etc., may play a role in how we remember a particular view.[35] For example, when viewing objects, there are canonical views that people find most aesthetically pleasing.[36,37] Memory for the particular view of an object is biased toward this canonical view.[38,39] Interestingly, such memory and systematic biases are taken as evidence for an optimal memory system.[40] If there is any uncertainty in our memory for a particular view, an optimal memory system will combine this information with existing expectations about the kinds of views we are likely to see.

In scenes, as with objects, there is evidence for canonical or preferred views. For example, viewpoint positions that are preferred provide a centred balance view of layout.[41] Furthermore, memories for spatial layout are stored with a preferred orientation.[42,43] Konkle and Oliva[44] examined the question of a prototypical viewing distance of a scene by having observers navigate forward and backward through a space and select the best view. Using stimuli similar to those used in the current experiment, they showed that observers consistently choose a preferred view in the middle of the image series.[15,39,44] Overall, the preferred view of a scene depends on the shape of the space, which is defined by the distances and layouts of the surfaces in the scene.

Our results showed that people with AMD have a greater central bias in the navigation task than do those in the control group. One possible explanation for this effect is that people with AMD

exhibit difficulties in constructing a memory representation of the prime scene. Indeed, because of their central vision loss, patients with AMD were likely to be improperly perceiving the prime view and thus recalling the improperly encoded image. They would therefore be more subject to the influence of "false" memory in their navigation task. This assumes that the middle view of the scene is a "canonical" view, which is consistent with the results, because the middle view showed no systematic memory distortions. We suggest that people with AMD may be relying on canonical scene views to compensate for their impoverished (peripheral only) perception of the scene.

Our results also showed that people with central vision loss navigate accurately when a middle scene was presented, as do normally sighted controls. In other words, although people with AMD had stronger systematic biases than the controls, they were able to perform the task in general using peripheral vision. This is consistent with previous findings that the peripheral visual field provides important global spatial information used in the development of spatial representations.[24,25] For example, Fortenbaugh et al.[25] found that peripheral vision loss was associated with distortions in spatial representations, which increased with a decreasing field of view.

Finally, no correlation was found between the virtual spatial navigation performance and clinical variables such as visual acuity, size of the lesion, and visual field defects. This finding is consistent with Cahill et al.[45] who reported no correlation between the lesion size and peripheral vision, and we also found no correlation between lesion size and scene gist recognition in our previous work.[19] However, it is important to acknowledge limitations of the present work to detect such an effect. First, the sample was relatively small. Second, conventional perimetry used in this study does not allow exact measurements of the size of the absolute scotoma. Third, head and eye tracking gaze strategies were not analyzed to determine the compensatory strategies used by participants with AMD. This will be examined in a further study.

In conclusion, the present study demonstrates two effects of memory for a spatial location in a scene. First, all observers exhibited a hysteresis effect when navigating to a remembered location: they tended to not walk far enough to get to the exact location and so their memory was biased, based on their starting position. Second, all observers showed a systematic bias toward the center of the room. Participants with AMD showed stronger center biases, suggesting that they rely more on their memory of a "canonical" view, which is a middle view of these scenes. The present findings may help to explain some of the difficulties in navigation[14] in patients with AMD.[45]

ACKNOWLEDGMENTS

The authors are grateful to Aude Oliva and to Talia Konkle who provided the images used in the study and for their helpful comments on the initial version of the article.

Received December 12, 2013; accepted May 16, 2014.

REFERENCES

1. Klaver CC, Wolfs RC, Vingerling JR, Hofman A, de Jong PT. Age-specific prevalence and causes of blindness and visual impairment in an older population: the Rotterdam Study. Arch Ophthalmol 1998; 116:653–8.
2. Smith W, Assink J, Klein R, Mitchell P, Klaver CC, Klein BE, Hofman A, Jensen S, Wang JJ, de Jong PT. Risk factors for age-related macular degeneration: pooled findings from three continents. Ophthalmology 2001;108:697–704.
3. Scott IU, Smiddy WE, Schiffman J, Feuer WJ, Pappas CJ. Quality of life of low-vision patients and the impact of low-vision services. Am J Ophthalmol 1999;128:54–62.
4. Mangione CM, Lee PP, Gutierrez PR, Spritzer K, Berry S, Hays RD. Development of the 25-Item National Eye Institute Visual Function Questionnaire. Arch Ophthalmol 2001;119:1050–8.
5. Soubrane G, Cruess A, Lotery A, Pauleikhoff D, Mones J, Xu X, Zlateva G, Buggage R, Conlon J, Goss TF. Burden and health care resource utilization in neovascular age-related macular degeneration: findings of a multicountry study. Arch Ophthalmol 2007;125:1249–54.
6. Wood JM, Lacherez PF, Black AA, Cole MH, Boon MY, Kerr GK. Postural stability and gait among older adults with age-related maculopathy. Invest Ophthalmol Vis Sci 2009;50:482–7.
7. Hassan SE, Lovie-Kitchin JE, Woods RL. Vision and mobility performance of subjects with age-related macular degeneration. Optom Vis Sci 2002;79:697–707.
8. Elliott DB, Patla AE, Flanagan JG, Spaulding S, Rietdyk S, Strong G, Brown S. The Waterloo Vision and Mobility Study: postural control strategies in subjects with ARM. Ophthalmic Physiol Opt 1995; 15:553–9.
9. Spaulding SJ, Patla AE, Elliott DB, Flanagan J, Rietdyk S, Brown S. Waterloo Vision and Mobility Study: gait adaptations to altered surfaces in individuals with age-related maculopathy. Optom Vis Sci 1994;71:770–7.
10. Kuyk T, Elliott JL. Visual factors and mobility in persons with age-related macular degeneration. J Rehabil Res Dev 1999;36:303–12.
11. Marron JA, Bailey IL. Visual factors and orientation-mobility performance. Am J Optom Physiol Opt 1982;59:413–26.
12. Soong GP, Lovie-Kitchin JE, Brown B. Does mobility performance of visually impaired adults improve immediately after orientation and mobility training? Optom Vis Sci 2001;78:657–66.
13. Kuyk T, Elliott JL, Biehl J, Fuhr PS. Environmental variables and mobility performance in adults with low vision. J Am Optom Assoc 1996;67:403–9.
14. Patel I, Turano KA, Broman AT, Bandeen-Roche K, Munoz B, West SK. Measures of visual function and percentage of preferred walking speed in older adults: the Salisbury Eye Evaluation Project. Invest Ophthalmol Vis Sci 2006;47:65–71.
15. Oliva A, Park S, Konkle T. Representing, perceiving and remembering the shape of visual space. In: Harris LR, Jenkin MRM, eds. Vision in 3D Environments. Cambridge, UK: Cambridge University Press; 2010:308–40.
16. Oliva A, Torralba A. Building the gist of a scene: the role of global image features in recognition. Prog Brain Res 2006;155:23–36.
17. Greene MR, Oliva A. Recognition of natural scenes from global properties: seeing the forest without representing the trees. Cogn Psychol 2009;58:137–76.
18. Greene MR, Oliva A. The briefest of glances: the time course of natural scene understanding. Psychol Sci 2009;20:464–72.
19. Tran TH, Rambaud C, Despretz P, Boucart M. Scene perception in age-related macular degeneration. Invest Ophthalmol Vis Sci 2010;51:6868–74.
20. Boucart M, Despretz P, Hladiuk K, Desmettre T. Does context or color improve object recognition in patients with low vision? Vis Neurosci 2008;25:685–91.

21. Tran TH, Guyader N, Guerin A, Despretz P, Boucart M. Figure ground discrimination in age-related macular degeneration. Invest Ophthalmol Vis Sci 2011;52:1655–60.
22. Grill-Spector K, Malach R. The human visual cortex. Annu Rev Neurosci 2004;27:649–77.
23. Turano KA, Schuchard RA. Space perception in observers with visual field loss. Clin Vis Sci 1991;6:289–99.
24. Fortenbaugh FC, Hicks JC, Hao L, Turano KA. Losing sight of the bigger picture: peripheral field loss compresses representations of space. Vision Res 2007;47:2506–20.
25. Fortenbaugh FC, Hicks JC, Turano KA. The effect of peripheral visual field loss on representations of space: evidence for distortion and adaptation. Invest Ophthalmol Vis Sci 2008;49:2765–72.
26. Schmitz-Valckenberg S, Bultmann S, Dreyhaupt J, Bindewald A, Holz FG, Rohrschneider K. Fundus autofluorescence and fundus perimetry in the junctional zone of geographic atrophy in patients with age-related macular degeneration. Invest Ophthalmol Vis Sci 2004;45:4470–6.
27. Holz FG, Bindewald-Wittich A, Fleckenstein M, Dreyhaupt J, Scholl HP, Schmitz-Valckenberg S. Progression of geographic atrophy and impact of fundus autofluorescence patterns in age-related macular degeneration. Am J Ophthalmol 2007;143:463–72.
28. Kaiser PK, Blodi BA, Shapiro H, Acharya NR. Angiographic and optical coherence tomographic results of the MARINA study of ranibizumab in neovascular age-related macular degeneration. Ophthalmology 2007;114:1868–75.
29. Cheung SH, Legge GE. Functional and cortical adaptations to central vision loss. Vis Neurosci 2005;22:187–201.
30. Schuchard RA. Preferred retinal loci and macular scotoma characteristics in patients with age-related macular degeneration. Can J Ophthalmol 2005;40:303–12.
31. Swaine W. The relation of visual acuity and accommodation to ametropia. Trans Opt Soc 1925;27:9–27.
32. Tarita-Nistor L, Brent MH, Steinbach MJ, Brent SE, Gonzalez EG. Spatial distortion in age-related macular degeneration. Invest Ophthalmol Vis Sci 2012;53:E-abstract 4384.
33. Intraub H, Bodamer JL. Boundary extension: fundamental aspect of pictorial representation or encoding artifact? J Exp Psychol Learn Mem Cogn 1993;19:1387–97.
34. Intraub H, Gottesman CV, Bills AJ. Effects of perceiving and imagining scenes on memory for pictures. J Exp Psychol Learn Mem Cogn 1998;24:186–201.
35. Hemmer P, Steyvers M. Integrating episodic and semantic information in memory for natural scenes. In: Taatgen N, van Rijn H, eds. Proceedings of the 31st Annual Conference of the Cognitive Science Society. Austin, TX: Cognitive Science Society; 2009:1557–62.
36. Palmer SE, Rosch E, Chase P. Canonical perspective and the perception of objects. In: Long J, Baddeley A, eds. Attention and Performance IX. Hillsdale, NJ: Erlbaum; 1981:135–51.
37. Konkle T, Oliva A. Canonical visual size for real-world objects. J Exp Psychol Hum Percept Perform 2011;37:23–37.
38. Hemmer P, Steyvers M. A Bayesian account of reconstructive memory. Top Cogn Sci 2009;1:189–202.
39. Konkle T, Oliva A. Normative representation of objects: Evidence for an ecological bias in perception and memory. In: McNamara DS, Trafton JG, eds. Proceedings of the 29th Annual Cognitive Science Society. Austin, TX: Cognitive Science Society; 2007:407–13.
40. Huttenlocher J, Hedges LV, Vevea JL. Why do categories affect stimulus judgment? J Exp Psychol Gen 2000;129:220–41.
41. Waller D. Egocentric and nonegocentric coding in memory for spatial layout: evidence from scene recognition. Mem Cognit 2006; 34:491–504.
42. Shelton AL, McNamara TP. Systems of spatial reference in human memory. Cogn Psychol 2001;43:274–310.
43. Shelton AL, McNamara TP. Visual memories from nonvisual experiences. Psychol Sci 2001;12:343–7.
44. Konkle T, Oliva A. Normative representation of objects and scences: evidence from predictable biases in visual perception and memory. J Vis 2007;7:1049.
45. Cahill MT, Banks AD, Stinnett SS, Toth CA. Vision-related quality of life in patients with bilateral severe age-related macular degeneration. Ophthalmology 2005;112:152–8.

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