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Visual factors and mobility in persons with age-related macular degeneration

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Abstract —

The objectives of this study were to determine the effects of reducing light level on mobility performance in persons with age-related macular degeneration (ARMD) and how performance relates to measures of visual sensory and perceptual function. ARMD results in the loss of central, high-acuity vision and is the leading cause of vision loss in veterans participating in the blind rehabilitation programs of the Department of Veterans Affairs. In 41 subjects with ARMD acuity, peak letter contrast sensitivity, visual field extent, glare disability, color confusion, spatio-temporal contrast sensitivity, motion sensitivity, scanning ability, and figure-ground discrimination were measured to determine their ability to predict mobility performance. Mobility performance was assessed under photopic (high illumination) and mesopic (low illumination) lighting conditions on a laboratory obstacle course and two real-world courses, an indoor hallway and an outdoor residential route. Reducing illumination resulted in significant increases in the time to complete each course and the number of mobility incidents (errors) that occurred. Two measures of overall performance, total time and total mobility incidents, were calculated for each course by summing time and incidents over the two illumination levels. Combinations of vision variables were able to account for 30 to 60% of the variance in the measures of overall performance. Log contrast sensitivity measured with the Pelli-Robson chart test and visual field extent were the most important predictors of performance. Other variables making significant contributions to prediction in multi-predictor models included: scanning ability, glare sensitivity, color confusion, and peak contrast sensitivity to drifting gratings.

Key words: adaptation level, low vision, mobility performance, visual function, visual impairment.

INTRODUCTION

Age-related macular degeneration (ARMD) is the leading cause of blindness in older adults. It is also the leading cause of vision loss in veterans entering the blind rehabilitation programs of the Department of Veterans Affairs (VA), accounting for approximately 33 percent of admissions. ARMD is characterized by the development of central scotomas, loss of central vision and reduced acuity (1). Other vision deficits associated with the disease include reduced contrast sensitivity (CS; 2,3), problems adapting to changing levels of illumination (2,4), abnormalities in temporal processing (5), and color vision (6). Despite the changes in vision, the general clinical impression is that persons with central vision loss have few mobility problems. However, they are not free of them, as persons with macular disease report increased difficulty traveling in low illumination and in detecting elevation changes, such as curbs, in the travel surface (7).

It makes intuitive sense that significant visual deficits would have an impact on mobility performance. This premise is supported by a number of studies of the effects of partial sight loss on mobility that have shown that measures of visual function such as visual acuity, CS, residual visual field, differential velocity sensitivity, and scanning ability (SCN) are predictive of mobility performance (8-16). In addition, it has been found that visually impaired persons have greater difficulty with mobility in poor illumination (10,13-16). However, it is presently not clear whether these findings generalize to persons with ARMD. Two earlier studies reported no difference in mobility performance between subjects with ARMD and those with normal vision under photopic (10,17) and mesopic (10) lighting conditions, no significant decline in performance under mesopic conditions (10), and no significant correlations between performance and measures of visual function conditions (10,17). Only when illumination was reduced to scotopic (rod) levels did one study report a significant decline in performance and a difference between ARMD and nonimpaired subjects (10). However, measures of mobility and visual function remained uncorrelated for this lighting condition.

In contrast, we previously reported that subjects with central vision loss took longer to complete an obstacle avoidance task and made more errors under mesopic conditions, and that mobility performance in both photopic and mesopic illumination was predicted by measures of visual function (14). Several factors may account for the differences among the three studies. First, approximately 35 percent of our central-vision-loss group was made up of persons with diseases other than ARMD. It is possible their performance and vision characteristics were different and that this significantly influenced our results. However, we think the differences can probably be attributed to other factors. Second, the mobility tasks in both of the ARMD studies were much simpler than the ones we used. It is possible that these simple tasks did not adequately challenge the subjects and as a result were insensitive to all but very large differences in performance. Third, in the study of ARMD that explored the effects of varying illumination level on performance (10), the majority of subjects appeared to have relatively good vision. For example, six of the ten subjects with ARMD had near normal visual acuity (20/32 or better). The pairing of mild visual impairment with simple tasks might explain why the ARMD subjects performed at the level of normal subjects under all but the most difficult visual conditions.

These problems were addressed in the present study by employing more difficult and complex mobility tasks and ARMD subjects whose level of visual impairment covered a broad range. The aims of the present study were to: 1) determine the effects of reducing illumination level on performance, and 2) determine the visual factors that predict mobility performance in ARMD.

METHODS

Subjects

Subjects were 45 veterans with ARMD who were clients of the VA's Southeastern Blind Rehabilitation Center. Persons whose medical records indicated their mobility was not restricted because of physical or health conditions were recruited for the study. The nature and possible consequences of the study were described to each individual. Each was then asked whether he or she felt physically able to walk the mobility courses that had been described. The veterans who used long canes were asked whether they would be willing to walk the courses without them. Persons who replied in the negative to these questions were excluded from participation. The remaining individuals who agreed to participate signed informed consent. The research followed the tenets of the Declaration of Helsinki and was approved by the University of Alabama at Birmingham's institutional review board on human use.

Four subjects were eventually eliminated from the sample because they refused to walk one of the mobility courses under mesopic conditions. The reason given was that they could not see well enough to do so. This yielded an ARMD sample of 41 subjects with a mean age of 72.79 years (±6.09 years).

Vision Assessment

All subjects underwent a battery of tests of sensory and perceptual visual function. These tests were administered binocularly except for the test of disability glare (DGL). The sensory tests included: 1) high contrast distance visual acuity in units of the logarithm of the minimum angle of resolution (log MAR; 18). 2) High contrast DGL also in log MAR was determined in the better eye in the presence of a glare source provided by the Brightness Acuity Tester set at its medium intensity setting. A DGL score was calculated as the difference between acuity scores with and without the glare source present. A positive score indicates a loss of acuity in the presence of the glare source (19). 3) CS (in log CS) was measured with the Pelli-Robson chart (20). 4) Color confusion was measured with the standard Farnsworth Dichotomous Test Panel D15 (21). The measure was a confusion-index score that ranged from 1 (normal) to 4 (22). 5) Visual field extent (VFE) was measured binocularly along 12 meridians with a Goldmann perimeter and III/4/e target at standard background luminance. Results were in degrees of field remaining along each meridian and the values for the twelve meridians were summed to yield the measure of VFE (23). Since there was no statistical advantage in doing so, VFE was not expressed as a percent of an arbitrary or "normal" binocular visual field as in other studies (8,9,11). 6) Spatial CS functions measured using a Nicolet Optronics vision tester at five spatial frequencies (0.5, 1, 3, 6, and 11.4 cycles per degree of visual angle) with stationary sine wave gratings, and 7) with gratings drifting at 3.75 Hertz (Hz). 8) Motion sensitivity was measured on the same system with a 0.5 cycle per degree sine wave grating drifting at frequencies between 0.5 and 15 Hz. Both spatial CS and the motion sensitivity functions were fit with second order polynomials and four quantitative variables were derived from each fit, yielding a total of twelve vision variables. Examples of fits to motion sensitivity functions for ARMD subjects and normal observers are shown in **Figure 1.** Average functions are shown in these examples, but in practice fits were made to data from each subject. The four variables derived from these and similar fits to the spatial CS data included log CS at the lowest frequency tested, maximum or peak log CS, the frequency in Hz or cycles per second where maximum log CS occurred, and high frequency cut-off in Hz or cycles per second taken at the point where the fitted function intersected the abscissa.

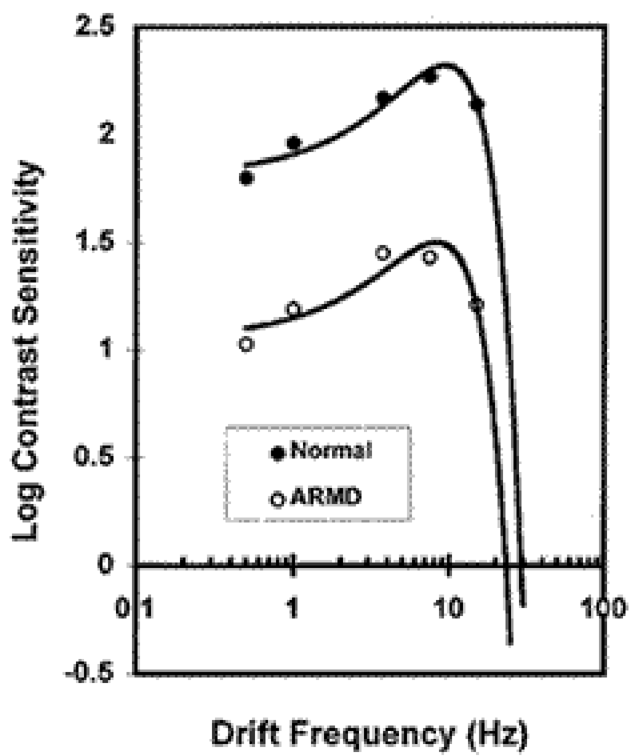

Figure 1. Average motion sensitivity data for a sample of 12 nonimpaired (filled circles) and 41

ARMD (open circles) subjects. Solid curves drawn through the data points are second order polynomial fits.

The three perceptual tests included: 1) Figure-ground discrimination ability where subjects identified simple geometric shapes in sets of overlapping shapes (24). The number of shapes in the sets varied from 2 to 5. The measure of performance was the number of correctly identified shapes out of 15 total shapes. 2) Embedded figures discrimination where subjects located geometric shapes embedded in distracters of varying complexity (24). The performance measure was the number of correctly located shapes out of 20 total shapes. 3) SCN where subjects located, in sequence, as many numbered targets as possible from a sequential set of 13 high-contrast number targets (1 through 13) that were randomly distributed (overlaid) on a black and white photograph of a street scene (25). The performance measure was the number of targets located in the second of two 10-s trials.

Mobility Assessment

Three mobility courses were used, a high-density obstacle course set up in a laboratory, an indoor hallway course laid out in a Medical Center setting, and an outdoor course laid out in a residential/small business environment. Schematic diagrams and detailed descriptions of these courses have appeared in previous publications (15,26). Furthermore, performance on the laboratory obstacle course was found to be significantly correlated with performance on the real world courses (15). Of the 41 subjects, all were tested on the obstacle course, approximately half (n=19) were tested on the hallway course, and the remainder (n=22) on the outdoor course. Subjects were instructed to walk the courses at as rapid a pace as felt comfortable, but at the same time to maintain safety, stay on the course, and avoid making contact with any objects in or along the edge of the course. They were told they would be timed and that a spotter would always follow closely behind them to insure their safety. On the real-world courses, they were also told their walks would be videotaped.

Briefly, the obstacle course consisted of a pathway 1-1.5 m wide and 30.5 m long that wound through several rooms of a laboratory. Boundaries of the course included walls, doorways, cabinets, and lab benches, but in open areas boundaries were marked on the white linoleum floor by 10-cm dark blue tape. In addition to these potential obstacles, the course was seeded with 60 objects, mostly foam cylinders, placed in the travel path. Some were laid across the path and had to be stepped over to be avoided, others projected upward from the floor or protruded horizontally into the path from knee to chest level, and others were suspended from the ceiling. Although they varied in size, even the smallest objects were relatively large. Approximately half were white and half dark gray so that against the white linoleum floor and walls they had contrasts of 6-10 percent or 75-90 percent. The course was illuminated by overhead fluorescent lights, which yielded average floor and wall luminances of 80 and 62 cd/m^2, respectively.

The hallway course consisted of 154 m of halls and stairs on two floors in a medical center. The halls were wide and well illuminated by overhead fluorescent lights, which gave an average surface luminance of 62 cd/m^2. Obstacles consisted of chairs along walls, crash carts, cabinets, small tables, a copy machine, housekeeping carts, and pedestrians. The course had two start points that provided two routes that ran in approximately opposite directions. Each started on an upper floor, went down one floor, and then back up, ending at the original start point. Stairs were used to travel between floors, and subjects had to pass through six doors on each route.

The outdoor course consisted of two different routes laid out in a mixed residential and small business environment. Route 1 was 305 m in length and route 2 was 350.5 m in length. The travel path was primarily on sidewalks and consisted of smooth and broken surfaces with numerous shaded locations. Regularly occurring obstacles included broken pavement, protruding tree branches and shrubbery, posts, telephone and streetlight poles, signs, and curbs. Other obstacles included pedestrians, a garden hose, dogs, trashcans, and automobiles parked across or along the walkway. There were three street crossings on each route. Average surface luminance (measured at 25 locations) was 2,250 cd/m^2 on sunny days and 1,140 cd/m^2 on mostly cloudy days.

Testing on each course was conducted under photopic (normal ambient) and mesopic (reduced or dim) illumination conditions with subjects wearing their normal prescription. Mesopic illumination conditions were achieved with wrap-around neutral gray sun shades (NoIR), under which subjects wore their prescription. One sunshade was used on the obstacle and hallway courses. It had a neutral density of 1.47 log units and reduced average floor luminances on the two courses to 3.4 and 2.5 cd/m^2, respectively. Two different sunshades were used on the outdoor course. One was for mostly sunny days and another was for mostly cloudy or overcast days. The first had a neutral density of 2.5 log units, the second 2.2 log units, and they both reduced average surface luminance to approximately 7 cd/m^2. Favorable weather conditions in the Southeast allowed most outdoor testing to be performed on sunny or partly sunny days, thus the second pair of sunshades had only occasional use. The direction of the walks through the courses (or choice of outdoor route) was counterbalanced across the two lighting conditions.

Measures of mobility on the obstacle course were travel time and number of mobility incidents. A mobility incident was defined as any contact with an object in the course or with the course boundaries. Travel time and mobility incidents were also measured on the two real-world courses. However, mobility incidents on these courses were more broadly defined to include the occurrence of behaviors in the following categories: 1) object contacts; 2) searches with hands or feet; 3) losses of balance (tripping, falling, or obvious body instability usually observed as stumbling or lurching); 4) abnormal foot placements that interrupted the normal gait but may or may not have led to a loss of balance (e.g. high stepping, hard stepping, side stepping, over-stepping, short-stepping, and shuffling; 5) going off path; 6) trailing (intermittent or constant hand contact with a structure forming a path boundary); 7) unwarranted stops; 8) spotter interventions (verbal or physical); 9) missed landmarks: see Long et al. (9) for description of a similar procedure. The mobility measures on the real-world courses were extracted from the videotapes. Incidents were operationally defined and scored by two mobility instructors whose inter-rater reliability was r=0.96.

RESULTS

Vision Tests

Table 1 lists the mean and standard deviation for each of the 20 vision measures. Vision in the

ARMD sample was not normal as indicated by the common clinical tests of high contrast acuity, Pelli-Robson CS, color vision, and VFE. Acuity ranged from 0.6 to 1.58 log MAR with an average of 1.23. This is equivalent to a Snellen acuity of 20/340. Pelli-Robson CS ranged from 0 to 1.65 with an average of 0.67 compared to a normal range of 1.6-1.9.

Table 1.

Vision test results.

Vision Test	Test Abbreviation	Mean	SD
High Contrast Acuity in logMAR	log MAR	1.23	0.30
Glare Disability in logMAR	DGL	0.06	0.16
Pelli-Robson Log Contrast Sensitivity	Log CS	0.68	0.39
Color Confusion Index	D15	2.51	0.70
Visual Field Extent in degrees	VFE	576.0	119.87
Figure-Ground, number of targets correct out of 15	F/G	14.32	1.67
Embedded Figures, number of targets correct out of 20	EMB	11.67	3.64
Scanning, number of targets correct out of 13	SCN	3.49	1.69
Low Frequency Log Contrast Sensitivity (Motion)	LFSM	1.06	0.41
Peak Log Contrast Sensitivity (Motion)	PSM	1.71	0.74
Drift Frequency in Hz at Peak Contrast Sensitivity (Motion)	PFM	7.35	2.3
High Frequency Cut-off in Hz (Motion)	CUTM	22.15	3.87
Low Frequency Log Contrast Sensitivity (Stationary gratings)	LFSS	0.76	0.52
Peak Log Contrast Sensitivity (Stationary gratings)	PSS	1.19	0.48

Frequency in cpd at Peak Contrast Sensitivity (Stationary gratings)	PFS	2.55	1.70
High Frequency Cut-off in cpd (Stationary gratings)	CUTS	7.86	4.29
Low Frequency Log Contrast Sensitivity (Drifting gratings)	LFSD	1.38	0.47
Peak Log Contrast Sensitivity (Drifting gratings)	PSD	1.44	0.48
Frequency in cpd at Peak Contrast Sensitivity (Drifting gratings)	PFD	1.13	1.04
High Frequency Cut-off in cpd (Drifting gratings)	CUTD	8.59	4.15

Persons with normal color vision have a color confusion index score of 1. Mean VFE was 577 degrees, about 68 percent of the standard full visual field defined by the VA and Social Security Administration for disability rating purposes and obtained using the same test procedures (23). Other examples of abnormal visual function can be seen in **Figures 1** and **2,** which show average motion sensitivity and spatial CS functions for the ARMD sample compared with results from subjects with normal vision. In each case, the functions for ARMD subjects lie about a log unit below the normal curves, and the peaks of the functions are shifted toward lower frequencies. Similarly, normal SCN scores for subjects in their sixties and seventies average between 7 and 8 (targets located), compared to a mean score of 3.5 for the ARMD sample. Normal values for the figure-ground and embedded figures tests are not available.

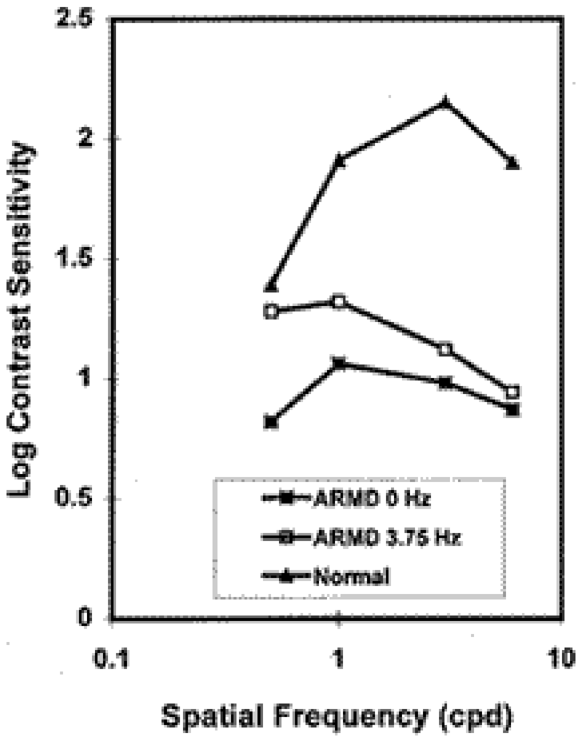

Figure 2. Average spatial contrast sensitivity data for 41 ARMD subjects obtained with stationary (0 Hz) or drifting (3.75 Hz) sine wave gratings. Included for comparison are data taken from Owsley et al. (27) for normal subjects in their 70's. Curves drawn through the data points are not polynomial fits.

Mobility Performance and Illumination

Table 2 shows that for all three mobility courses, reducing the illumination level from photopic to mesopic resulted in significant increases in mean travel times and mobility incidents. Mean travel times on the obstacle, hallway, and outdoor courses increased by 36, 38, and 25 percent, and the mean number of mobility incidents increased by 97, 110, and 195 percent, respectively.

Table 2.

Mobility performance results.

Task		Condition		
		Photopic*	Mesopic*	Dependent t-test
Obstacle (n=41)	Time	76.6 (24.6)	104.4 (44.9)	t=-4.41, p<0.001
	Incidents	2.7 (2.8)	5.46 (4.01)	t=-4.94, p<0.001

Hallway (n=19)	Time	246.9 (42.6)	339.7 (118.9)	t=-4.01, p<0.01
	Incidents	9.7 (10.8)	20.37 (13.1)	t=-4.22, p<0.01
Outdoor (n=22)	Time	384.04 (80.5)	480.9 (145.4)	t=-3.14, p<0.01
	Incidents	7.3 (8.0)	21.62 (15.5)	t=-5.76, p<0.001

* = mean (SD).

To compare performance on the different courses as well as with results from other studies, mean travel times were converted to mean walking speeds (m/s). **Figure 3** shows that mean walking speed was lowest on the obstacle course and highest on the outdoor course. For the obstacle course, walking speeds in the photopic and mesopic conditions were 0.40 and 0.29 m/s, respectively. On the hallway course they were 0.62 and 0.45 m/s, and for the outdoor course, 0.83 and 0.66 m/s. Statistical analysis showed that the effect of mobility course was significant for both lighting conditions (photopic F=67.78, p<0.00001; scotopic F=40.29, p<0.00001). As would be expected from the statistical analysis of the travel time data (see **Table 2**), walking speed on all courses declined significantly under mesopic conditions.

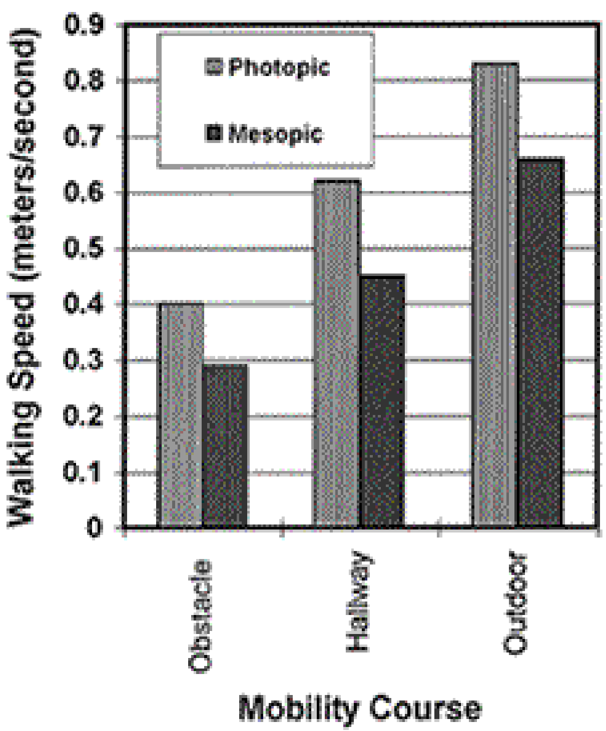

Figure 3. Mean walking speed in ARMD subjects as a function of mobility course and illumination level.

Mobility Performance and Visual Characteristics

With, depending on the task, sample sizes of 19, 22, and 41 subjects, it was impossible to conduct meaningful multiple regression analysis using all 20 vision variables. The number of variables had to be reduced, and this was achieved using factor analysis in combination with correlation and step-wise regression. The factor analysis indicated the vision variable set could be represented by eight hypothetical variables. The clustering of variables within the eight dimensions suggested that seven of the dimensions corresponded to the following general visual factors: CS (six variables), spatial resolution (four variables), temporal resolution (two variables), glare sensitivity (one variable), color confusion (one variable), perceptual function (three variables), and visual fields (one variable). In the eighth dimension, log CS and log MAR had high and moderate factor loadings, respectively. The distribution of variables in eight dimensions was similar to that found when the same variable set for a larger heterogeneous sample of visually impaired adults was factor analyzed (14,15).

Correlation and step-wise regression were used to develop predictive models for each travel situation and dependent variable. The general rule of thumb for multivariable regression models is that the sample contain 6 to 10 subjects for each variable in the model. Thus, for the obstacle course with an n of 41, the maximum number of variables was restricted to 5. For the hallway and outdoor courses, with n of 19 and 22, respectively, models consisted of a maximum of 3 variables. For time on the obstacle course, the best variable set consisted of five variables, Pelli-Robson CS (Log CS), SCN, peak sensitivity to drifting gratings (PSD), DGL, and high spatial frequency cut-off for drifting gratings (CUTD). The best set for incidents on the obstacle course saw VFE substituted for log CS with the other variables remaining the same as in the previous set (SCN, PSD, DGL, and CUTD). For performance on the hallway course, three variables (Log CS, VFE, D15) were used to form models for both time and incidents. Similarly, the best set for the outdoor course consisted of three variables (Log CS, PSD, and DGL) that were used for both time and incidents.

Table 3 shows the final step-wise regression results. Significant models were found in all three travel situations for the performance measures total time and total incidents (indicated in boldface). These two variables are indicators of overall performance and were created by summing time spent on course or number of incidents for the two illumination conditions. Predictor variables are listed from left to right in order of importance in the models. Other models listed in the table are for time or mobility incidents for each course and adaptation condition. There are no variables listed for time to complete the hallway course under mesopic conditions and number of incidents on the outdoor course under photopic conditions, because statistically significant models of performance in these situations were not obtained.

Table 3.

Predictor variables for performance on all courses.

Performance Measure	Predictor Variables	R^2

		OBSTACLE COURSE			
Total Time	**Log CS***	**SCN**	**DGL**	**CUTD**	**0.39[b]**
Photopic Time	SCN	Log CS	DGL		0.22[a]
Mesopic Time	Log CS	DGL	SCN	CUTD	0.40[c]
Total Incidents	**VFE**	**SCN**	**DGL**	**CUTD**	**0.33[b]**
Photopic Incidents	VFE	SCN	DGL		0.21[a]
Mesopic Incidents	VFE	SCN	DGL	CUTD	0.31[b]
		HALLWAY COURSE			
Total Time	**Log CS**	**D15**			**0.35[a]**
Photopic Time	Log CS	D15			0.33[a]
Mesopic Time					0.33
Total Incidents	**Log CS**	**VFE**	**D15**		**0.60[b]**
Photopic Incidents	Log CS	VFE	D15		0.57[b]
Mesopic Incidents	VFE	D15			0.36[b]
		OUTDOOR COURSE			
Total Time	**Log CS**	**PSD**	**DGL**		**0.44[b]**
Photopic Time	DGL	Log CS*	PSD		0.35[a]
Mesopic Time	Log CS	PSD	DGL		0.37[a]
Total Incidents	**Log CS**	**PSD**			**0.30[a]**
Photopic Incidents					0.09

Mesopic Incidents	Log CS	PSD	0.36[a]

[a]=p <0.01; [b]=p <0.01; [c]=p <0.001; * LogCS=Pelli-Robson contrast sensitivity; SCN=scanning ability; DGL=glare disability; CUTD=high spatial frequency cut-off for drifting gratings; VFE=visual field extent; D15=color confusion; PSD=peak contrast sensitivity for drifting gratings.

Considering only the measures of overall performance, **Table 3** shows that on the obstacle course, the variables log CS, SCN, DGL, and high CUTD formed a model that accounted for 39 percent of the variance in total time spent walking this course. For total incidents, log CS dropped out of the model and was replaced by VFE, which in combination with the other three variables accounted for 33 percent of the variance in total incidents. A fifth variable, PSD, was put into the analysis but did not significantly improve prediction; hence, it is not listed in the table.

For the hallway route, log CS was the most important predictor of both time and incidents and color confusion (D15) appeared in both models. Log CS and D15 were able to account for 35 percent of the variance in total time and the combination of log CS, VFE, and D15 accounted for 60 percent of the variance in total incidents. Log CS was also the most important predictor of performance on the outdoor course. Combined with PSD and DGL, it accounted for 44 percent of the variance in total time, and in combination with PSD, 30 percent of the variance in total incidents.

DISCUSSION

This study demonstrates that reducing illumination from photopic to mesopic levels has an adverse affect on mobility in persons with ARMD. Travel times on all mobility courses increased significantly as subjects responded to reduced illumination by walking more slowly. Despite their slowing down, abnormal mobility behaviors increased significantly in all travel situations. These findings are consistent with results for heterogeneous samples of visually impaired older adults and persons with retinitis pigmentosa (RP; 13-16). However, they are in conflict with another study of ARMD subjects that reported no differences in mobility performance between photopic and mesopic lighting conditions (10). We believe the conflicting results can be attributed to between-study differences in the level of difficulty of the mobility tasks and the degree of visual impairment of the ARMD subjects. Brown et al. (10) used relatively simple mobility tasks and we did not. This factor alone may account for most of the difference between studies. If the simple tasks had minimal visual requirements for successful completion, then it follows that they might not be sensitive to the effects of less severe visual deficits on performance. Second, our ARMD subjects were more significantly impaired visually than those of Brown et al. Mild impairment combined with the use of simple tasks may explain why Brown et al. found that reducing illumination from photopic to mesopic levels had no effect on mobility performance in their ARMD subjects.

We also found that reducing illumination had a more adverse effect on mobility incidents than on travel time. Furthermore, across the three mobility situations reducing illumination had similar effects on the percent increase in travel times, but not on the number of mobility incidents. The percent increase in travel times ranged from 25-38 percent, whereas the number of mobility incidents increased by approximately 100 percent on the two indoor courses but by almost 200 percent on the outdoor course. Although these two findings are consistent with results for heterogeneous samples, they remain largely unexplained (15). The lesser effect on travel times compared to incidents could have occurred if subjects adopted a travel strategy that sacrificed safety for speed. However, it is not clear why they would do this, nor is it apparent that the test instructions would have biased them in this direction. On the other hand, the effect may have arisen because subjects had less experience in low light conditions at setting a pace that optimized the trade-off between walking speed and mobility incidents.

A factor that may have contributed to the larger percent increase in incidents on the outdoor course under mesopic conditions is the size of the absolute change in light level. The difference between the photopic and mesopic conditions outdoors ranged from approximately 1,100 to 2,200 cd/m^2 whereas indoors the difference was less than 100 cd/m^2. However, this explanation seems inconsistent with reports by subjects of no subjective difference between vision indoors and in daylight outdoors and with the relative stability of visual function over a wide adaptation range (11). Until the effects of light level on mobility performance in visually impaired persons are better understood, this factor cannot be ruled out, nor can the possibility that it interacted in some way with differences in the characteristics of the indoor and outdoor courses (e.g. smooth versus uneven surfaces).

This study also found significant correlations between ARMD subjects' visual characteristics and measures of overall performance as well as for performance under photopic and mesopic conditions. Two previous attempts in ARMD subjects found the opposite (10,17). Again we attribute the conflicting results to between-study differences in the level of difficulty of the mobility tasks and the degree of visual impairment of the subjects.

The results of step-wise regression analysis showed, with one exception, CS was the most important predictor of overall performance (total time and total incidents) in all three mobility situations. This finding is consistent with several other studies, which cited CS as one of the two most important predictors of performance (8,9,11,16). The second variable cited by these studies was VFE. However, in the present study, we found VFE was a significant predictor in only two of six models of overall performance. Furthermore it was paired only once with log CS. The relative absence in our models of a measure of the visual fields may indicate that it is a visual characteristic that is not as important to mobility in ARMD as it is to other groups (e.g., RP). Either that, or there is a problem with the way we measured field extent that, for unknown reasons, affected the ARMD results differently than it did those of other subject groups in our other studies (14,15).

Visual acuity is another factor that is often found to be highly correlated with mobility performance, and there has been some conflict over whether visual acuity or log CS is the most important predictor of mobility performance (8,10-12,16). Among those citing acuity as an important variable are Brown et al. Although they did not find vision measures to be correlated with mobility in ARMD in a specific lighting condition as we did, they did find vision measures were significantly related to the ratio of performance in the light to that in the dark. In their prediction equations for this ratio, visual acuity always carried the most weight. However, in the present study visual acuity was not a significant predictor variable (see **Table 4**). Since Brown et al. did not measure log CS, we do not know whether it would have replaced visual acuity in their models for ARMD subjects.

In addition to log CS and VFE, several other visual characteristics made significant contributions to the prediction of mobility performance. Most of these are unique to this study. The other important variables included SCN, PSD, glare sensitivity and color confusion. It is primarily these variables that account for the uniqueness of the variable sets between mobility situations, and it suggests there may be differences in the visual requirements of each task. For example, SCN was an important predictor of performance on the obstacle, but not the real-world, courses. It makes intuitive sense that good scanning skills would be important in a situation where there are many turns and a very high density of objects at different levels, but not so important in a uniform environment with a very low density of objects to avoid. In contrast, it is not intuitively obvious why color confusion was only an important predictor in the hallway situation, which like the obstacle course was remarkably achromatic, or why PSD, which is a dynamic measure log CS, was only important in the outdoor situation.

Lastly, we found a gradation of walking speeds going from the slowest for the obstacle course to the fastest for the outdoor course. This result is not particularly surprising given the nature of the travel environments. The obstacle course was narrow, had a number of sharp turns, and was very crowded with objects. Both the hallway and outdoor routes were comparatively wide open with relatively long straight sections, although the hallway route had more turns and progress was slowed by having to negotiate two sets of stairs and six doorways. In general, our walking speed data compare well with those from other studies. Brown et al. (10) reported a walking speed of approximately 0.67 m/s for their ARMD subjects on an indoor slalom course under photopic conditions. This number is close to the 0.62 m/s rate on our most comparable route, the hallway course. In this study the mean travel rate on the obstacle course was 0.40 m/s, which corresponds quite well to the 0.42 m/s rate reported by Lovie-Kitchin et al. (12) for a comparable test condition. In contrast, Geruschat et al. (16) reported a mean walking speed of approximately 1.16 m/s in subjects with RP in a naturalistic environment, nearly double that of our most closely comparable condition, the hallway course, and 40 percent faster than the rate on the outdoor course. This difference seems somewhat surprising since RP subjects report more difficulty with mobility than persons with ARMD (7). However, the much slower pace in the ARMD subjects may be mostly an aging effect, as the mean age of our ARMD sample (72.8 years), was nearly 30 years greater than that of the RP sample of Geruschat et al. (44.4 years).

CONCLUSIONS

Reduced illumination impairs mobility in ARMD and performance is most highly correlated with log CS. Depending on the specific travel conditions and dependent measures (time on course or incidents) other visual characteristics, including SCN, VFE, glare sensitivity, color confusion, and peak contrast sensitivity to a moving target are also important predictors of performance.

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