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Article

Low Light Exposure and Physical Activity in Older Adults With and Without Age-Related Macular Degeneration

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Purpose: To investigate the extent of low light exposure and associated physical activity in older adults with and without age-related macular degeneration (AMD).

Methods: Light exposure (lux) and physical activity (counts per minute, CPM) were measured in 28 older adults (14 bilateral AMD and 14 normally sighted controls) using a wrist-worn actigraphy device (Actiwatch) for 7 days and nights. Exposure to low light levels (≤10 lux) and physical activity during waking hours were determined, as well as number of brief active periods during sleeping hours (e.g., going to the bathroom). Assessments included visual acuity and the Low Luminance Questionnaire (LLQ).

Results: No significant differences were found in low light exposure (39 ± 14% vs. 34 ± 10%) or physical activity (200 ± 82 CPM vs. 226 ± 55 CPM) during waking hours between the AMD and control group. However, the AMD group had more brief active periods during sleeping hours than controls (1.8 ± 1.3 vs. 1.1 ± 0.4; $P = 0.007$). Reduced physical activity under low light levels was significantly associated with lower LLQ scores ($P = 0.012$).

Conclusions: Exposure to low light levels and associated physical activity were similar in older adults with and without AMD. This has important implications for older adults with AMD, given the impact of low light levels on visual function and mobility, suggesting the need for including lighting advice in rehabilitation programs for this population.

Translational Relevance: Older adults with and without AMD spend over a third of waking hours under low light levels, which are an environmental falls hazard. Findings suggest the need for interventions to improve lighting levels for older adults.

Introduction

Ambient light levels play an important role in the ability to undertake activities of daily living, particularly those relating to safe mobility. Indeed, many older adults, even those with normal vision, report difficulties in performing many daily activities under low light levels,[1,2] which include indoor environments, such as poorly lit bedrooms, bathrooms, or kitchens at nighttime, and outdoor environments, such as carparks or pavements (footpaths or sidewalks) at night. Importantly, difficulties under low light conditions are exacerbated in older adults with vision impairment associated with age-related macular degeneration (AMD).[3–7] These self-reported difficulties are also reflected in decreased postural control (balance)[8] and increased mobility problems[9–11] under low light levels. Importantly, falls risk is also higher in older adults with AMD compared to those with normal vision under photopic light levels[12,13] and may be exacerbated under low light levels due to further decreases in vision under low lighting conditions in those with AMD.[4,14,15] However, the extent to which older adults with AMD are exposed to low light conditions is unknown, which is a key research gap, given the increased difficulty with activities of daily living under low light levels reported in those with vision impairment from AMD.[3–7]

Studies have reported average daily light exposure across the 24-hour cycle in adults of different ages,[16–18] but only a limited number of studies have specifically explored exposure to low light levels (≤10 lux).[19,20] Cole et al.[19] reported that adults (age range 21–76 years) spent an average of 47% of the 24-hour cycle under these low light levels, and Espiritu et al.[20] reported that middle-aged adults (age range 40–64 years) spent an average of 63% of the 24-hour cycle under these light levels. However, these two studies did not differentiate between light exposure during waking and sleeping hours. In two studies that explored exposure to low light levels (1–10 lux) specifically during waking hours, older adults were reported to spend around a quarter (23%–25%) of their awake time under these light levels.[21,22] Understanding the extent to which older adults are exposed to low light levels during both waking and sleeping hours is important, as many mobility-related activities (e.g., moving around the house at night; walking outdoors at dawn, dusk, or at night; going to the bathroom during sleeping hours at night) occur in low lighting conditions, which have been shown to be an important environmental hazard for falls in older adults both with and without vision impairment.[23,24]

It is also important to consider the level of physical activity of older adults, both with and without AMD, especially under low light levels, given their reports of mobility-related difficulties under these conditions. Studies have reported lower levels of physical activity in older adults with AMD in general, although not specifically under low light levels. For example, Loprinzi et al.[25] showed that older adults with late stage AMD engaged in significantly less (50% lower) moderate-to-vigorous physical activity than those without AMD, and Sengupta et al.[26] reported that older adults with AMD took significantly fewer steps, engaged in less physical activity and took fewer excursions away from home compared to their visually normal counterparts. Knowledge of the levels of physical activity of older adults with AMD under low light levels would provide important insight into their level of risk under these conditions.

Exploration of the brief active periods that may occur during sleeping hours at night, such as getting out of bed to use the bathroom or to get a drink of water, is also important, as these activities may be a risk factor for falls given the potential for low lighting conditions or light–dark adaptation changes associated with sudden changes in lighting. Rod-mediated dark adaptation has been shown to be delayed in older adults both with and without AMD,[27–30] and this may increase falls risk given that dark adaptation is impaired in older adults classified as fallers compared to non-fallers.[31] A preliminary study reported that collisions with obstacles, such as furniture, were increased under low light conditions and contributed to falls in older adults when getting out of bed at night, such as to go to the bathroom.[24] Although some studies have reported overall light exposure (22–51 lux) in older adults at night, either during entire sleeping hours or during the time period from sunset to sunrise,[32,33] light exposure specifically during brief active periods during sleeping hours at night and associated levels of physical activity are not known in older adults, either with or without vision impairment from AMD.

The purpose of this study was to measure exposure to low light levels and associated physical activity during waking hours, as well as the brief active periods during sleeping hours, over seven consecutive 24-hour periods in a cohort of older adults with and without AMD. Although previous studies have examined the association between AMD and physical activity levels in general, this study also explored whether the level of physical activity under different light levels in older adults with AMD was associated with binocular visual acuity and self-reported low luminance visual difficulties. We hypothesized that those with more severe loss of binocular visual acuity or greater low luminance visual difficulties would reduce their levels of physical activity to a greater extent, particularly under low light levels, as a compensatory measure.

Methods

Study Design and Participants

This observational cross-sectional study included 28 community-dwelling older adults aged 65 years and older: 14 with bilateral AMD (mean age ± SD, 83.9 ± 7.0 years) and 14 controls with normal vision (74.6 ± 3.3 years). Participants were recruited from the Queensland University of Technology (QUT) Optometry Clinic and the laboratory's existing database of participants. Ethics approval was obtained from the QUT Human Research Ethics Committee, and informed written consent was obtained before commencement of the study. The study adhered to the tenets of the Declaration of Helsinki.

Participants with AMD had a confirmed diagnosis of AMD and best-corrected visual acuity of 6/9 or worse in the better eye; controls had no ocular disease (other than early lens opacities) and best corrected visual acuity of 6/7.5 or better in both eyes. Participants with eye diseases other than AMD and early lens opacities, including visually significant cataract, corneal diseases, glaucoma, optic nerve problems, and other retinal problems were excluded. Participants unable to walk unaided or with any known history of dizziness or vestibular disease, with a history of stroke or brain injury, or with known cases of neurological conditions, medications affecting balance, or any signs of cognitive impairment (Mini-Mental State Examination score of less than 24)[34] were also excluded.

Data were collected on sociodemographic details (age, gender) and medical information (self-rated health, medical history, and current medication use). Participants were also asked to rate their overall balance status using a single question (response options: very poor, poor, fair, good, or excellent). Information on self-reported falls in the previous 12 months was recorded, where a fall was defined as coming to rest unintentionally on the ground, floor, or any lower level.[35,36]

Vision Assessment

An eye examination was conducted using slit-lamp biomicroscopy and binocular indirect ophthalmoscopy. The presence and severity of any lens opacification were graded according to the Lens Opacities Classification System (LOCS III),[37] and participants with LOCS III 3 or higher were excluded.[15,38,39] Color fundus photographs were taken with a Canon Digital Non-Mydriatic Retinal Camera (Canon USA, Huntington, NY). The photographs were graded according to drusen size and pigmentary changes by one of the authors, who is an experienced optometrist (MKD), to confirm the categorization of participants into those with AMD and controls, based on the Beckman classification scale.[40] Monocular and binocular high-contrast visual acuity were measured with the participant's habitual distance refractive correction with an Early Treatment of Diabetic Retinopathy Study chart (Good-Lite, Elgin, IL), at a distance of 4 m and average luminance of 130 cd/m^2. Charts that incorporated different optotypes were used to minimize any learning effects. Visual acuity was scored letter by letter, in logMAR units, with a termination rule of three or more errors on a line.[41] Participants with severe visual impairment, who were unable to read letters on the chart from the standard testing distance of 4 m, were tested at closer distances and scored accordingly.[41]

Low Luminance Questionnaire

Visual difficulties under low luminance were assessed using a self-administered questionnaire, the 32-item Low Luminance Questionnaire (LLQ).[5] This questionnaire consists of six subscales: driving, extreme lighting, mobility, emotional distress, general dim lighting, and peripheral vision. The LLQ scores were computed using the scoring procedures described previously.[5] Responses to the 32 items were scored on a scale ranging from 0 to 100, with 0 indicating the greatest difficulty and 100 indicating no difficulty under low luminance. The items associated within each subscale were averaged to generate subscale scores, and the LLQ composite score was calculated as the average of the subscale scores.

Measurement of Ambient Light Exposure and Physical Activity

Ambient light exposure and physical activity were measured for 7 consecutive days and nights[19,42,43] using an Actiwatch 2 (Philips Respironics, Murrysville, PA). The Actiwatch is a wristwatch-style device comprised of a photodiode light sensor to record ambient light exposure (in lux) and a solid state piezoelectric accelerometer to objectively measure physical activity (as counts per minute [CPM]).[44] The accelerometer in the Actiwatch records the amount and intensity of movement in all directions within a 1-minute epoch, which provides an estimate of physical activity quantified as CPM.[45] The Actiwatch has been reported to have excellent between-device agreement for both light exposure and activity.[46] Similar actigraphy devices have been used for measuring outdoor light exposure and physical activity,[46–48] as well as low light exposure,[49] in children and adults. Although Actiwatch devices have been shown to underestimate the true illuminance values at higher photopic light levels,[50] recent research has assessed the validity of the Actiwatch device and supports its use for recording illumination levels in real-world settings across a broad range of light levels.[51]

Data were collected from the Brisbane area in Queensland, Australia (latitude 27.48°S, longitude 153.04°E) over a period of 14 months (representing all four seasons across the year, with daylight hours ranging from 10.5–13.5 hours). The watch was worn on the non-dominant wrist[42,46] for 24 hours a day except when swimming or showering for longer than 30 minutes, which is the water-resistant period of the device.[46,48] Participants were given verbal and written instructions on the use of the device, including positioning the light sensor to avoid any obscuration by clothing. The Actiwatch was programmed to record ambient light exposure and activity at a 15-second sampling rate for seven consecutive 24-hour periods from 5:00 AM on the first day to 5:00 AM on the morning of the eighth day.

A validation study was undertaken to compare the Actiwatch illuminance readings (sampling at 15 seconds) to those of calibrated illuminance and luminance meters under controlled laboratory conditions and to determine the light categories for the analysis (see Supplementary Material). In brief, lighting levels were set at a series of low to high mesopic (0.1, 0.5, 1, and 3 cd/m^2)[52] and photopic (10 and 150 cd/m^2) luminance levels as measured using a calibrated luminance meter (LMK 5 color, video photometer, TechnoTeam Bildverarbeitung GmbH, Ilmenau, Germany). For each of these luminance levels, Actiwatch readings at both the eye and at wrist level were compared to those of an illuminance meter. From the findings of the validation study, based on the Actiwatch measurements at wrist level, values of ∼ 20 lux were obtained at high mesopic luminance levels (3 cd/m^2). Under low to high mesopic levels, the Actiwatch sensor showed high agreement with the luxmeter (mean difference, ∼0.71 ± 0.81 lux). Based on this validation study, ambient light levels were categorized into the following three levels: scotopic to mid-mesopic (≤10 lux; low light levels), which approximates to luminance levels up to 1 cd/m^2; high mesopic (>10 to ≤30 lux), which approximates to luminance levels around 3 cd/m^2; and photopic (>30 lux), which approximates to luminance levels around 10 cd/m^2 and higher, reflecting typical daytime indoor and outdoor light levels. Additionally, to illustrate real-world examples of low light situations, ambient light levels were recorded using the Actiwatch for several indoor and outdoor environments at nighttime. The mean illuminance values obtained in these situations were below 10 lux—for example, pavements along the street (≤7.2 lux) or carparks (3.6 lux) at nighttime or a bedroom with a table lamp on (2.6 lux) (see Supplementary Material).

While wearing the Actiwatch, each participant also maintained a 7-day diary where they self-reported their waking and bed times, any periods when they removed the Actiwatch (swim/shower), days and times when they did not wear the Actiwatch, and the number of times they got out of bed during sleeping hours, such as to go to the bathroom.[53] Participants were contacted by phone during the third and the fifth day to ensure compliance with wearing the device and maintenance of the diary. Before participants commenced wearing the Actiwatch device, they also completed questionnaires regarding their self-reported use of room lights in the bathroom or bedroom while getting out of bed during the night, and use of any light source during sleeping hours at night.

Analyses of Actiwatch Data

Light exposure and physical activity data were analyzed using the manufacturer's software (Actiware, version 6.09), which determines the sleep start and sleep end for each measurement day, based on the validated algorithm of the activity data recorded,[54–56] and the data were cross-checked with the participants' diaries. Waking hours (out-of-bed periods) were defined as the time between wake-up time and bedtime, and sleeping hours were defined as the time period between bedtime and wake-up time, as determined by the Actiwatch software. Although these sleeping and waking hours were based on objectively collected data from the Actiwatch, participants' self-reported bedtime and wake-up times from the diary were compared with Actiwatch data to confirm sleeping and waking hours. In instances where the Actiwatch software incorrectly coded sleeping hours (for example, sleeping hours coded during the day that did not correspond with self-reported diary data), the data were manually adjusted to reflect the diary data by changing sleeping to waking hours. Light exposure and physical activity data were analyzed separately for waking and sleeping hours.

Waking Hours Data Analyses

Data collected during waking hours were screened to remove any invalid data before further analysis. Any continuous intervals of ≥15 minutes of no recorded activity (non-wear time) and/or complete darkness at 0.01 lux or lower but exhibiting some activity during waking hours (evidence of light sensor being obscured by clothing) were considered invalid.[46,48] However, as this was naturalistic study, all other data, including any nap periods, were included in the analysis, given that some individuals might take a nap during the day, during which they may exhibit very low levels of physical activity (e.g., arm moving around).

Data screening and cleaning were undertaken using a custom code written in MATLAB R2018a (Math Works, Natick, MA). The cleaned data were further screened for the total period of wear time during waking hours for each day. Data were considered valid if the participants had at least 4 days of 10 or more hours per day of valid wear time.[25,57,58] If the watch was worn for less than 10 hours during waking hours in any day, that day was excluded from further analyses,[42,57] leading to the exclusion of 2 days for one AMD participant and 1 day for another AMD participant.

The mean time spent (expressed as the percentage of total valid waking hours) and physical activity (quantified as activity in CPM) undertaken under scotopic to mid-mesopic (low light, ≤10 lux), high mesopic (>10 to ≤30 lux), and photopic (>30 lux) were calculated for each day and then averaged for the number of days worn. The mean physical activity was calculated by dividing the sum of activity counts by the number of minutes of wear time.[47,59] The mean light exposure and physical activity over the 7 days during waking hours were also calculated.

In addition, the chronological distribution of light exposure during waking hours was explored and categorized into three time periods: morning (wake-up to midday), afternoon (midday to 6:00 PM), and evening (6:00 PM to bedtime). The mean time spent under each category of light levels in these time periods was expressed as a percentage of total waking hours within that time period.

Sleeping Hours Data Analyses

A brief active period during sleeping hours refers to activity that indicates movement out of bed at night and was defined as continuous activity of more than 2 minutes duration and at light-to-moderate levels of physical activity (274 CPM or greater).[42] The number of brief active periods per night, percent of time lights were turned on during all active periods, average light exposure (lux), and physical activity (CPM) during each brief active period during sleeping hours at night were calculated for each participant and averaged across the nights where data were available. For active periods, maximum light exposure greater than 30 lux was classified as when lighting was turned on, based on values for high mesopic luminance levels or higher (see Supplementary Material).

Statistical Analysis

Statistical analyses were performed using SPSS statistics 25.0 (IBM, Armonk, NY), and the level of significance was set at $P < 0.05$. Group differences for categorical variables (gender, health and balance status, and number of previous fallers) were assessed using χ^2 tests. For continuous variables (age, visual acuity, the LLQ composite score and number of falls), independent-samples *t*-tests were used. Group differences in time spent and physical activity under different light levels and overall light exposure and physical activity during waking hours were assessed using univariate general linear models, both unadjusted and adjusted for age, gender, and season (four categories), considering them as covariates, to account for group age and gender differences and seasonal variations in the amount of daylight hours. Group differences in the number of brief active periods per night, percent of time lights were turned on, light exposure, and associated physical activity were assessed using univariate general linear models, both unadjusted and adjusted for age and gender.

To investigate the effect of light levels on the percentage of time spent across different light level categories and associated physical activity, linear mixed models with maximum likelihood estimation were conducted. Time spent and physical activity were defined as dependent variables; categorical variables such as light levels (three light categories) and group (control vs. AMD) were included as fixed factors; and participants' intercepts were included as random effects in the model, assuming a variance components covariance structure for the random effects. To further account for potential confounding factors, differences in light exposure and physical activity between groups were adjusted for age, gender, and season. Pairwise comparisons were performed (Bonferroni adjusted) for any significant main effects and interactions. The associations among binocular visual acuity, LLQ composite score, and physical activity were assessed using linear regression models, both unadjusted and adjusted for age and gender.

Results

The AMD group (83.9 ± 7.0 years) was significantly older than the control group (74.6 ± 3.3 years) ($P < 0.001$). The proportion of females was higher in the AMD group (64%) compared to the control group (29%), but this difference failed to reach significance ($P = 0.06$). The AMD group had significantly poorer self-rated health status than the controls ($P = 0.04$); almost all of the control participants (∼93%) rated their health as "very good" to "excellent" compared to ∼43% of the AMD participants. There were no differences between the AMD and control group for non-ocular comorbidities (3.9 ± 2.4 vs. 2.3 ± 1.4; $P = 0.45$) or the use of systemic medications (6.6 ± 4.3 vs. 2.6 ± 2.2; $P = 0.10$), adjusted for age.

Table 1 summarizes the self-rated balance status, falls characteristics, binocular visual acuity, and LLQ composite scores for the AMD and control groups. There were no significant differences in self-reported balance ($P = 0.43$), number of previous falls ($P = 0.35$), or the number of previous fallers ($P = 0.65$) between the AMD and control groups. The mean binocular visual acuity ($P < 0.001$) and mean LLQ composite score ($P < 0.001$) were significantly worse in the AMD compared to the control group.

Waking Hours Light Exposure and Physical Activity

The number of valid waking hours was significantly lower in the AMD group compared to controls (13.9 ± 1.6 vs. 15.4 ± 1.2; $P = 0.009$), with more invalid data for the AMD group compared to the control group (10.8% ± 6.7 vs. 4.8% ± 2.6; $P = 0.005$), indicating that Actiwatch non-wear time and obscuration by clothing were greater in the AMD group compared to the control group. The number of valid days was not different between the AMD and control groups (6.8 ± 0.6 vs. 7.0 ± 0.0; $P = 0.18$).

Table 1. Self-Rated Balance Status, Falls Characteristics, Binocular Visual Acuity, and LLQ Composite Scores for the AMD and Control Groups

Characteristics	Control Group (*n* = 14)	AMD Group (*n* = 14)	*P*
Self-rated balance status, *n* (%)			
Excellent or good	10 (71.4)	8 (57.1)	0.43
Fair or poor	4 (28.6)	6 (42.9)	
Falls in previous 12 mo, *n*			
Mean (SD)	0.21 (0.58)	0.64 (1.60)	0.35
Range	0–2	0–6	
Number of fallers, *n* (%)	2 (14.3)	4 (28.6)	0.65[a]
Binocular visual acuity (logMAR), mean (SD)	−0.10 (0.07)	0.57 (0.43)	**<0.001**
LLQ composite score, mean (SD)	89.0 (7.6)	49.5 (23.2)	**<0.001**

Independent samples *t*-test to determine the mean difference between groups; χ^2 test for categorical variables. Bold values indicate significant differences. LLQ, Low luminance questionnaire.
[a]Fisher's exact test.

Table 2. Overall Daily Light Exposure, Time Spent, and Physical Activity for the AMD and Control Groups Under Different Light Levels Over a 7-Day Period During Valid Waking Hours

	Mean (SD)			
	Control Group (*n* = 14)	AMD Group (*n* = 14)	Unadjusted *P*	Adjusted[a] *P*
Overall daily light exposure and physical activity				
Light exposure (lux)	662.4 (400.3)	458.6 (427.6)	0.20	0.91
Physical activity (CPM)	285.5 (78.5)	223.8 (74.2)	**0.042**	0.96
Time spent under different light levels (%)				
Scotopic to mid-mesopic (≤10 lux)	34.1 (10.2)	39.0 (14.1)	0.30	0.55
High mesopic (>10 to ≤30 lux)	17.8 (4.9)	18.8 (6.4)	0.65	0.92
Photopic (>30 lux)	48.1 (12.8)	42.2 (12.9)	0.23	0.73
Physical activity under different light levels (CPM)				
Scotopic to mid-mesopic (≤10 lux)	225.8 (55.4)	200.3 (82.3)	0.34	0.62
High mesopic (>10 to ≤30 lux)	259.8 (96.6)	237.7 (82.5)	0.52	0.26
Photopic (>30 lux)	355.2 (93.4)	258.8 (98.8)	**0.013**	0.80

Univariate GLM models were used to determine the mean difference between the groups. Bold values indicates significant differences. CPM, counts per minute.
[a]Adjusted for age, gender, and season.

The overall mean daily light exposure and physical activity and mean duration of time spent and associated physical activity across the three light level categories for the AMD and control group during valid waking hours are presented in Table 2 and Figure 1. Overall, there were no significant between group differences in mean daily light exposure (adjusted $P = 0.91$) or mean daily physical activity (adjusted $P = 0.96$).

For the time spent during valid waking hours under the different light categories, there was a significant main effect of light level ($F_{2,84} = 48.86$, $P < 0.001$), but no significant main effect of group ($F_{1,84} = 0.01$, $P = 0.99$), or group by light interaction ($F_{2,84} = 1.96$, $P = 0.15$), adjusted for age, gender, and season. Pairwise comparisons revealed that the greatest amount of time spent for all participants was under photopic levels (percent of mean ± SD, 45.1% ± 13.0), followed by scotopic to mid-mesopic levels (36.6% ± 12.3), with the least amount of time being spent under high mesopic levels (18.3% ± 5.6). Importantly, there were no significant between-group differences in the mean percent duration of time spent across each of the light levels (all, adjusted $P \geq 0.55$) (Table 2). Information regarding the percent of time spent for each light level category and time period during valid waking hours for all participants is presented in Table 3

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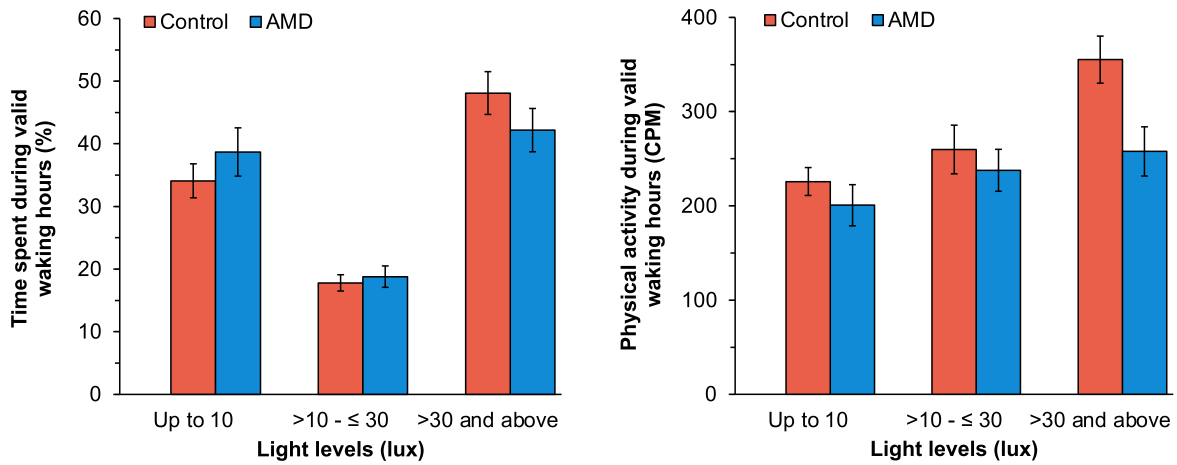

Figure 1. Percentage of time spent and physical activity (CPM) under different light levels over a 7-day period during valid waking hours. *Error bars* represent 1 standard error.

Table 3. Time Spent Under Various Light Levels Across Different Time Periods During Valid Waking Hours Over a 7-Day Period for All Participants

	Time Spent Under Various Light Levels During Valid Waking Hours (%), Mean (SD)		
Light-Level Categories	Morning	Afternoon	Evening
Scotopic to mid-mesopic (≤10 lux)	22.2 (15.9)	24.9 (14.3)	70.1 (14.4)
High mesopic (>10 to ≤30 lux)	17.0 (6.6)	20.1 (7.0)	19.0 (10.4)
Photopic (>30 lux)	60.8 (17.8)	55.0 (15.1)	10.9 (12.3)

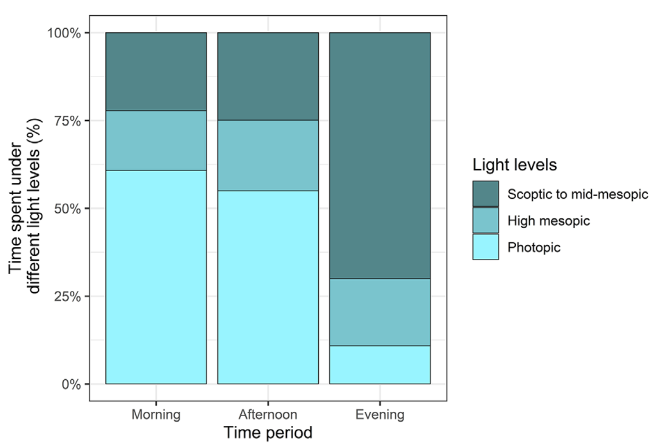

Figure 2. Time spent (percent) under different light levels as a function of time period during valid waking hours over a 7-day period for all participants.

and Figure 2. As expected, the greatest amount of exposure to low light levels was in the evening (over 70%). Importantly, older adults both with and without AMD spent nearly a quarter of time under low light levels, even during the morning and afternoon.

For physical activity during valid waking hours under the different light categories, there was a significant main effect of light level ($F_{2,56} = 20.77$, $P < 0.001$), and a significant interaction between group and light level ($F_{2,56} = 4.06$, $P = 0.023$), but no significant main effect of group ($F_{1,28} = 0.43$, $P = 0.52$), adjusted for age, gender, and season. Pairwise comparisons showed that the highest level of physical activity was under photopic light levels (mean $\pm$ SD, 307.0 $\pm$ 106.4 CPM), followed by high mesopic light levels (248.8 $\pm$ 88.9 CPM), with the least amount of activity occurring under scotopic to mid-mesopic light levels (213.1 $\pm$ 70.1 CPM). The significant group by light interaction effect showed that the AMD group exhibited significantly lower physical activity under scotopic to mid-mesopic light levels only ($P = 0.02$), whereas the control group exhibited significantly lower physical activity under both scotopic to mid-mesopic ($P < 0.001$) and high mesopic ($p < 0.001$) light levels, compared to photopic light levels. Importantly, there were no significant between-group differences for mean physical activity undertaken across each of the categories of light levels (all, adjusted $P \geq 0.26$) (Table 2).

Table 4. Associations Among Binocular Visual Acuity, LLQ Composite Score, and Physical Activity Under Different Light Levels for the AMD Group

	Unadjusted		Age and Gender Adjusted	
	Regression Coefficient (95% CI)	*P*	Regression Coefficient (95% CI)	*P*
Physical activity (CPM) under scotopic to mid-mesopic light				
VA (per 0.1 logMAR worse)	−10.24 (−20.46 to −0.01)	0.05	−12.31 (−26.85 to 2.22)	0.09
LLQ composite score (per 10 unit lower)	−17.06 (−36.65 to 2.52)	0.08	−26.57 (−53.6 to 0.47)	0.05
Physical activity (CPM) under high mesopic light				
VA (per 0.1 logMAR worse)	−10.27 (−20.52 to −0.01)	0.05	−5.84 (−19.66 to 7.98)	0.37
LLQ composite score (per 10 unit lower)	−27.42 (−41.70 to −13.13)	**0.001**	−27.77 (−47.81 to −7.72)	**0.012**
Physical activity (CPM) under photopic light				
VA (per 0.1 logMAR worse)	−12.19 (−24.51 to 0.13)	0.05	−7.03 (−23.91 to 9.85)	0.38
LLQ composite score (per 10 unit lower)	−20.31 (−43.89 to 3.27)	0.09	−13.2 (−46.09 to 19.68)	0.39

Bold values indicate significant differences. VA, visual acuity; CI, confidence interval; CPM, counts per minutes.

Given the range of visual impairment and the self-reported low-luminance visual difficulties in the AMD group, associations among binocular visual acuity, LLQ composite score, and physical activity under the three categories of light levels were explored for the AMD group only (Table 4). The association between reduced binocular visual acuity and lower physical activity across all light levels almost reached significance in the unadjusted analysis (all, $P = 0.05$); however, in the analysis adjusted for age and gender, these associations were not significant (all, $P \geq 0.09$) but exhibited trends toward lower physical activity under scotopic to mid-mesopic (low) light levels for those with greater reductions in binocular visual acuity. Lower LLQ composite scores (greater low luminance visual difficulties) were significantly associated with lower physical activity under high mesopic light levels in the unadjusted ($P = 0.001$) and adjusted ($P = 0.012$) analyses. Under scotopic to mid-mesopic conditions, these associations almost reached significance ($P = 0.05$) in the analysis adjusted for age and gender, but there were no significant associations under photopic light levels ($P = 0.39$).

Brief Active Periods During Sleeping Hours at Night

The number of brief active periods at night, percent of time lights were turned on during these active periods, associated physical activity, and average light exposure during the brief active periods at night are presented in Table 5. The number of brief active periods at night was significantly greater in the AMD compared to the control group, both in the unadjusted analysis ($P = 0.043$) and age and gender adjusted analyses ($P = 0.007$). However, there were no significant between-group differences in the proportion of time lights were turned on ($P = 0.28$), levels of physical activity ($P = 0.92$), or average light exposure ($P = 0.25$) during these brief active periods at night.

There were no significant differences in the self-reported use of bedroom lights when getting out of bed at night ($P = 0.68$), with 86% of controls and 71% of those with AMD never turning on the bedroom light. There were also no significant between-group differences in self-reported use of bathroom lights at night ($P = 0.11$), with 86% of controls and 43% of those with AMD never turning on the bathroom light. There

Table 5. Number of Active Periods, Percent of Time Lights Were Turned On, Physical Activity, and Light Exposure During Brief Active Periods at Night for the AMD and Control Groups Over a 7-Day Period

	Mean (SD)			
	Control Group ($n = 14$)	AMD Group ($n = 14$)	Unadjusted *P*	Age- and Gender-Adjusted *P*
Average number of brief active periods per night	1.1 (0.4)	1.8 (1.3)	**0.043**	0.007
Percent of time lights were turned on during brief active period[a]	16.8 (27.4)	20.5 (29.9)	0.74	0.28
Mean physical activity for brief active period (CPM)	380.2 (100.0)	348.9 (107.4)	0.43	0.92
Average light exposure (lux) for brief active periods	3.1 (5.7)	5.0 (6.4)	0.41	0.25

Univariate GLM models to determine the mean difference between the groups. Bold value indicates a significant difference.
[a]Where maximum light exposure during brief active period was greater than 30 lux.

were also no significant group differences in the number of participants who reported using any constant light source while sleeping at night, such as a dim nightlight or leaving some of the room lights on ($P = 0.54$), with 93% of controls and 86% of AMD not using constant night lighting.

Discussion

This naturalistic study demonstrated that older adults with and without AMD were exposed to low light levels (≤10 lux) for at least a third of their waking hours (39% and 34%, respectively). Importantly, there were no significant group differences in the time spent and associated physical activity under any of the light levels (scotopic to mid-mesopic, high mesopic, or photopic) during waking hours. Although the AMD group had more brief active periods at night, there were no significant between-group differences for the percent of time lights were turned on, light exposure, and associated physical activity for these events. Given that low lighting is likely to be an important environmental risk hazard for falls in all older adults,[23,60] these findings indicate that older adults in general may expose themselves to an increased risk of falls during normal everyday activities.

The finding that older adults with and without AMD spent over 30% of their awake time undertaking normal everyday activities under low light levels, is higher than previous estimates for similar light levels of 23% to 25% of awake time for older adults in general.[21,22] This discrepancy between previous findings may be attributed to the exclusion of light levels below 1 lux in previous studies, which considered these light levels as invalid data, potentially due to accidental obscuration of the light sensor[21,22]; thus, their findings are likely to underestimate the extent of exposure to low light levels. In the present study, all low light levels were included, except where it was determined that the sensor was likely to have been covered by clothing while worn, which was defined as light exposure data of 0.01 lux for any continuous period of 15 minutes or longer with corresponding activity. Moreover, previous studies[21,22] did not exclude times when the watch was not worn, as the valid data were based only on light level values and did not consider corresponding physical activity levels.

Importantly, exposure to low light levels was not significantly different between older adults with and without AMD during waking hours. This was unexpected, as we had hypothesized that older adults with AMD would have less exposure to low light levels compared to those without AMD, based on the premise that they would either avoid low light conditions or increase lighting levels where possible, due to their greater visual difficulties under low light levels.[3–7] It has been suggested that older adults in general spend most of their day (approximately 80%) in their homes,[61] and the findings of the present study indicate that older adults with AMD either do not modify their home visual environment by increasing lighting around the home or fail to avoid low lighting environments at or away from their home, and thus are exposed to similar levels of low light as their normally sighted counterparts.

However, it is important to note that an individual can only control lighting levels in some environments, such as their home indoor environments. Even in the home, the level of lighting control may also depend on other users within the home if living with others, and the design of the living space. Importantly, there are many indoor and outdoor environments that do not allow any control of lighting, such as indoor movie theaters, outdoor pavements, and carparks at night. Furthermore, older adults with AMD may lack awareness of the hazards of low light levels and the potential benefits of increasing light levels and may not consider using additional lighting to compensate for their visual difficulties under low light levels. These findings highlight the need for increased education for patients with AMD, regarding both the importance of well-designed home lighting and understanding their limitations when outdoors when lighting levels cannot be controlled, in order to reduce mobility problems and falls risk.

Our findings also demonstrate that physical activity in older adults in general was reduced under low compared to other higher light levels involving low levels of physical activity (145–274 CPM).[42] This suggests that low lighting levels may be associated with more sedentary activities but may also reflect compensatory behavior. Although not significantly different, our findings showed a trend for lower physical activity levels across all of the light levels in the older adults with AMD compared to controls, which supports findings from previous studies demonstrating that older adults with AMD are less likely to be active compared to those with normal vision.[25,26]

Importantly, we also found that the association between reduced visual acuity and lower levels of physical activity in the AMD group approached significance under low light levels, whereas these associations were not significant under other light levels. These findings suggest that those with AMD may exhibit some level of compensation by reducing their activity levels under low light conditions due to their reduced vision to minimize falls risks. This finding is supported to some extent by a previous study which also reported no association between visual acuity and levels of moderate-to-vigorous physical activity in older adults with late AMD under normal lighting conditions.[25] A novel finding of this study was that greater levels of low luminance visual difficulties (as assessed with the LLQ) in older adults with AMD were significantly associated with reduced physical activity under scotopic to mid-mesopic and high mesopic but not photopic light conditions. These findings indicate that greater self-reported visual difficulties under low luminance could be a potential predictor of reduced physical activity under low light conditions in older adults with AMD, and may reflect a compensatory mechanism to reduce activity under these challenging visual conditions.

Another novel aspect of the present study was investigation of the brief active periods during sleep hours at night, such as getting out of bed to use the bathroom or get a drink of water, exploring the frequency and lighting patterns during these events. The average number of brief active periods per night was significantly greater in older adults with AMD (1.8 ± 1.3) compared to controls (1.1 ± 0.4). This may be due to the AMD participants being older than the control participants, given evidence that sleep quality reduces with increasing age.[62] Furthermore, poor sleep quality is more common among older adults with vision impairment in general compared to those with normal vision.[62] Importantly, although the mechanisms have not been well explored, research shows that postural balance and gait are impaired during mid-sleep awakenings in older adults in general, due to complex interactions among circadian phase, homeostatic pressure, and sleep stage,[63] and the frequent need to wake at night to go to the bathroom has been linked to increased risk of falls in older adults.[64,65] Therefore, the findings suggest that older adults with AMD may be at greater risk of falls when getting out of bed at night.

Overall, the average light exposure was very low in both older adults with and without AMD during brief active periods at night, indicating that bedroom or bathroom lights are typically not turned on when getting out of bed at night, which reflects the low levels of self-reported use of lights in the bedroom and bathroom at night. These findings are important, as poor lighting may be a contributing factor to falls in the home,[23] including in corridors, bathrooms, and bedrooms, which are common sites for falls.[66–68] Although the home environment and home hazards are likely to be familiar to older adults both with and without AMD, the risk of falls is higher in the home, regardless of vision impairment.[69–71] This is likely due to the fact that older adults typically spend a substantial time of their day in their homes, where they perform many of their daily activities,[61] thus increasing their risk of falls. Most older adults both with and without AMD in the present study did not use any constant dim night lighting, which may provide some low-level lighting to assist in nighttime mobility and minimize risk of falls.[72,73] Importantly, the use of bright room lighting when walking around the home at night also poses risks, particularly when moving between bright and dim lighting environments. For example, walking in a darkened room after turning lights off to go back to the bed at night may increase falls risk in older adults, particularly in those with AMD due to delays in dark adaptation compared to those with normal vision.[28,74,75] Therefore, it is important that future research explores the use of smart home lighting systems at night to improve balance and mobility and reduce the risk of falls, such as dim long-wavelength lighting, that may provide adequate lighting for mobility without disrupting dark adaption and circadian rhythms.

The findings of the current study should be considered in terms of its strengths and limitations. This is the first study, to our knowledge, to investigate exposure to low light levels and associated physical activity in older adults with and without AMD during waking and sleeping hours separately. Furthermore, it included objective measurement of light levels and physical activity using a well-established actigraphy device (Actiwatch), with a validation study to ensure that light levels categories reflect mesopic and photopic lighting levels.

Limitations of the study include the relatively small sample size and the lack of age matching between the AMD group and the control group. However, the groups were similar in terms of cognitive status and many health characteristics, and age was included as a confounding factor in the analyses to account for the between-group age differences. It would be useful to expand this study to include larger samples of age-matched older adults both with and without AMD to confirm these findings. Moreover, due to the small number of participants who reported one or more falls in the previous 12 months and lack of information regarding the time and lighting conditions under which these falls occurred, the relationship between falls and physical activity under low lighting levels was not examined. Furthermore, light levels measured using a wrist-based Actiwatch may not reflect light exposure at the eye. However, it has been suggested that wrist-based measurements are an acceptable alternative to light measurements at eye level because they provide a practical and unobtrusive method for longer duration ambulatory studies in naturalistic settings.[76] The data collected also did not provide information regarding the locations where exposure to low light levels occurred, such as whether it was indoors (e.g., home or away from home) or outdoors (e.g., walking in outdoor carpark or footpath at night).

In conclusion, the current study demonstrated that older adults both with and without AMD were exposed to low light levels for at least a third of their waking hours as part of their normal daily activities. Importantly, the extent of low light exposure and associated physical activity under these lighting conditions did not differ significantly between the AMD group and the control group. There were also no significant between-group differences in the percent of time lights were turned on, light exposure, and associated physical activity during active periods at night, although the number of brief active periods was higher in older adults with AMD compared to controls. The findings indicate that older adults fail to reduce their exposure to low light levels. It is important that older adults, particularly those with AMD, receive appropriate education regarding the importance of good lighting, given the likely risk of increased falls under low light levels. The results of this study suggest that appropriate light management would be useful to incorporate as a component of visual rehabilitation advice for older adults with AMD. Given that lighting is a modifiable environmental factor, there is potential for improving the lighting design of home environments by increasing home light levels, therefore, reducing falls risk in these individuals.

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