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Exploring Older Adults' Nighttime Trips to the Bathroom Under Different Lighting Conditions: An Exploratory Field Study

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Abstract

Purpose: The field study was to understand older adults' reactions to and use of different low-light conditions while walking to bathrooms in the dark in their homes. Low-light conditions included participants' usual nightlights and a destination-based LED strip lighting system. **Background:** Older adults encounter fall accidents while going to bathrooms at night due to low illuminance levels. They also fear falling due to previous fall histories or visual impairments. This field study tested and compared a destination-based LED strip lighting system with their usual nightlights on their movement and fear of falls. **Methods:** Fifteen older adults from an independent living facility participated in the within-subject design experiment, walking under two scenarios in random order: with usual nightlights turned on or with the destination-based LED strip lighting system turned on. Body-worn sensors were used to collect participants' movement behaviors, and subjective questionnaires were used to understand participants' anxiety under the two low-light conditions. Further, semi-structured interviews were conducted to understand their nightlight usage patterns and their evaluations of the destination-based LED strip lighting system. **Results:** Participants walked more smoothly under the destination-based LED strip lighting system scenario. However, the anxiety states were not statistically different between the two scenarios. **Conclusion:** Visual cues in the dark can benefit older adults' safe movement. However, the application of the lab-effective LED strip lighting system in home settings should consider older adults' floor plans and their furniture layout, both indoor and outdoor ambient lighting sources, and their lifestyles.

Keywords

older adults, nightlight, movement behaviors, Life Plan Retirement Community, floor plan

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Older adults' visual system changes as they age, such as decreased pupil size and retinal illuminance, increased lens density, reduced contrast sensitivity, and others (Erdinest et al., 2021). As a result, older adults experience a decline in visual capabilities; for example, older adults take longer to adapt to low-lit environments than younger adults (Erdinest et al., 2021). The difficulty of adapting to the darkness can be a potential fall risk factor for older adults, for example, going to the bathroom at night (Dionyssiotis, 2012). Thus, studies have proposed providing visual cues to help older adults walk safely in the dark while making sure the lighting intensity of the visual cues won't disrupt older adults' sleep (Figueiro et al., 2012; Figueiro et al., 2011; Lu et al., 2019). Figueiro and colleagues (2012) examined the effect of visual cues—installing the LED lights around a simulated doorframe under a lab-controlled dark environment—on older adults' weight transfer time. The study indicated that the simulated door-framed LED lights worked better than the nightlight plugged near the wall side; with the door-framed LED lights, older adults with a fall history experienced significantly less weight transfer time, indicating fewer fall risks (Figueiro et al., 2012). Built upon Figueiro's lab studies' findings, Thölking and colleagues (2020) installed Gight™, a LED strip installed along the path from the bed to the bathroom, which can be turned on with a motion sensor, in older adults' homes. They used a single-item questionnaire to examine the Gight's effects on older adults' overcoming fears of falls and sleep quality, respectively, and concluded that the Gight™ was beneficial to overcome the fear of falling and increase sleep quality among participants.

Previous studies (Figueiro et al., 2012; Figueiro et al., 2011) examined lighting effects on older adults' movement behaviors in a uniform floor plan. They did not consider the variations of participants' home settings, such as the furniture layout and floor plans. Although Thölking and colleagues conducted a study at participants' homes, the details of the participants' floor plans and furniture layout were not provided. Further, studies (Figueiro et al., 2012; Figueiro et al., 2011) only measured predefined behaviors, such as the weight transfer time and spatial–temporal gait parameters in the predefined routes. However, older adults' walking paths and movement behaviors were more complicated in their home settings than in the lab settings; for example, older adults might stop a few seconds to turn on lights or reach out to a piece of furniture for support and others. Kim and his colleagues (2021) suggested that lighting design for older adults should consider older adults' behaviors and their needs related to daily activities.

The current study tested and compared the destination-based LED strip lighting systems and participants' usual nightlights' effects on their movement behaviors and anxiety in the dark in their homes. The purposes of the study were to understand older adults' light usage patterns at night in their residential settings, analyze movement behaviors with the interaction of the dark surroundings and their furniture layout, discover older adults' impressions of the destination-based LED strip lighting system, and their suggestions for improving the LED strip lighting system. Accordingly, three research questions were summarized as follows.

Research Question 1.1: What are the typical nightlight usage patterns when participants go to the bathroom at night?

Research Question 1.2: How do participants operate their usual nightlights?

Research Question 2: What are the differences in participants' movement behaviors and anxiety between the destination-based LED strip lighting system and their usual nightlights while going to the bathroom in the simulated dark environments?

Research Question 3.1: What are the older adults' impressions of the destination-based LED strip lighting system?

Research Question 3.2: What are the older adults' suggestions for redesigning the destination-based LED strip lighting?

Methods

Ethical Considerations

This study was approved by the University of Florida Institutional Review Board (IRB201901881). Participants were recruited from the independent

Figure 1. The LED strip lighting system was attached to the bathroom door at each participant's home.

living at a local Life Plan Retirement Community, and all could walk independently without using walking-assistant devices. Each participant signed a consent form before the experiment.

Experiment Design

The experiment simulated a dark environment by blocking natural and artificial lighting at each participant's apartment or house. In the *first scenario*, only the usual nightlights (hereafter referred to as the nightlight) were turned on. In the *second scenario,* only the destination-based LED strip lighting system (hereafter referred to as the LED strip lighting system, Figure 1) was turned on. The color temperature of the LED lighting is 3,000 K, and the lumen is 1,549 (Commercial Electrics, Model # C624340). If measured on the floor within a radius of 61 cm (24 in.) under the LED strip lighting as suggested by the Illuminating Engineering Society (2020), the lighting meter cannot detect any illuminance level emitted from the LED strip lighting. The illuminance level emitted from the LED strip lighting around the doorframe was 0.01 foot-candle (fc) when the researcher placed a lighting meter very close to the LED strip lighting.

The experiment was a within-subject research design experiment (i.e., repeated-measures). Participants walked four times for each lighting scenario, and the lighting scenarios were arranged in random order.

Instrument and Assessment

Inertial measurement unit (IMU) sensors (Xsens MVN Awinda, Xsens Analyze, Xsens Technologies BV; Enschede, the Netherlands) were attached to each participant's lower body to collect movement behaviors, including gait performance, lower-limb kinematics, and trunk motion measures.

State-Trait Anxiety Inventory (STAI) was used to evaluate each participant's anxiety level (the fear of falling) after walking each lighting scenario. STAI is an evaluation tool assessing the symptom of anxiety with appropriate reliability and validity (Spielberger et al., 1983). There are 20 items for the STAI questionnaire, each item ranging from "not at all" to "very much so" (from 1 to 4), with a total score of 80. The higher score represented more anxiety.

Experiment Procedure

The experiment began after briefing the whole experiment process and getting consent from each participant. There were three stages for the experiment, including preparation work by documenting the layout of the furniture and measuring the illuminance levels of the simulated dark environment, collecting gait behaviors, and conducting interviews. The flowchart (Figure 2) detailed each step and an estimated time for each step of the experiment. The time for each step varied slightly due to different factors, such as each participant's home setting being different, and the time taken to complete questionnaires and interviews was different.

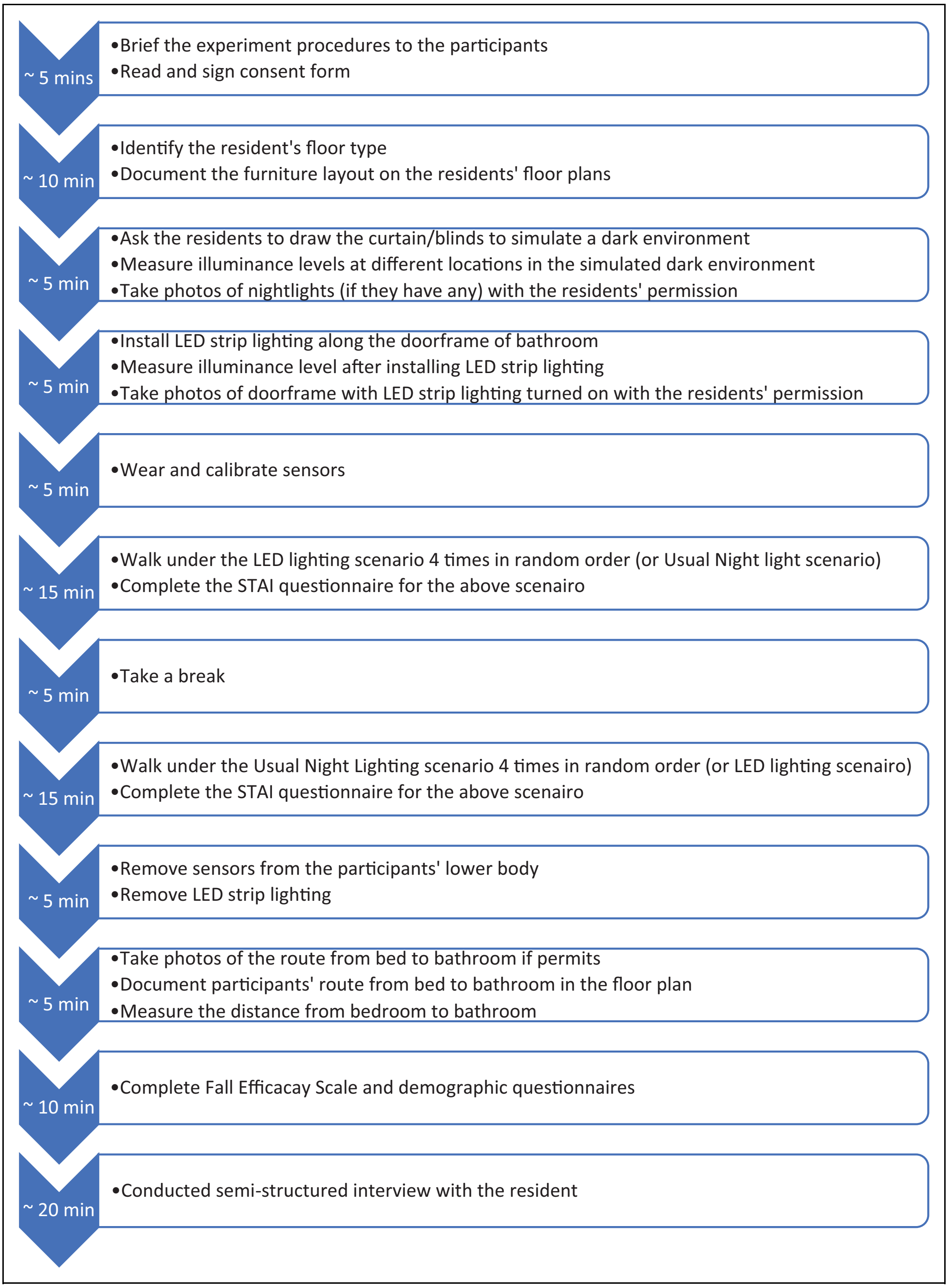

Figure 2. The flowchart of the experiment procedure.

In the stage of preparation, the researcher asked for each participant's floor plan type with prepared paper version floor plans of the Life Plan Retirement Community. With participants' permission, the researcher measured and documented the distance of the beds to the bathrooms' doorframes, measured the furniture sizes, and documented the furniture layout of participants' bedrooms on the printed floor plan for each participant.

Then, the researcher asked the participants to draw their curtains (if they had any) or blinds and turned off all the overhead lighting to simulate a dark environment. The researcher measured illuminance levels near the windows of the bedroom, near both sides of the bed, and near the bathroom doorframes of each participant's home and documented these illuminance levels on the printed floor plan. The researcher took photos of the nightlights at participants' homes with permission and documented the locations of the nightlights on the printed floor plan. Then, the researcher set up the LED strip lighting around the bathrooms' door frames and measured the illuminance levels emitted from the LED strip lighting in the simulated dark environment.

During the process of collecting gait behaviors, the researcher helped each participant wear the sensors and performed sensors' calibrations. Then, the participants walked in random order under two lighting scenarios. Participants walked four times under each scenario. Overall, it took about 15 min to collect each lighting condition scenario (including 10 min of walking trails and 5 min completing the STAI). To prevent tiredness, each participant was asked to take a break for approximately 5 min. And then the second lighting scenario data collection was performed. Once the two lighting scenarios' gait behaviors data collection was completed, the researcher helped the participants take off sensors and removed the LED strip lighting from the doorframe. The researcher drew each participant's route trajectory on the printed floor plan and documented the approximate walking distance.

In the stage of collecting subjective assessments, the researcher asked participants to fill out the Fall Efficacy Scales and demographic questionnaire, which took about 10 min. The last step was to conduct the interview with the participant, which took about 20 min. Specific details of the interview will be discussed in the "interview" section.

Floor Plans at the Life Plan Retirement Community

The experiment was conducted at a local Life Plan Retirement Community, which consisted of an independent living facility, assisted living facility, memory care residences, and private skilled nursing accommodations. This study was conducted at the independent living facility. The independent living facility of the Life Plan Retirement Community consists of 20 types of floor plans, including 16 apartments and four single-family houses.

Participants lived in 11 floor plans, including eight apartments and two single-family houses. Among them, two participants had the same floor plan as Figure 3, two had the same floor plan as Figure 4, three had the same floor plan as Figure 5, and the other eight participants had unique floor plans. In addition, two married couples participated in the study and shared the same floor plan and furniture layout (Figures 4 and 5). Among the 11 floor plans, 10 have a straight line from the bedroom to the bathroom, and one requires a turn between the bedroom and the bathroom (Figure 4).

Illuminance Levels at the Experiment Settings

A lighting meter (EXTECH, Model 401027, Nashua, NH, USA), with 5% accuracy, was used to measure the simulated dark environment. The lighting meter measured the ambient illuminance levels above the finished floor about 76 cm (30 in.; Illuminating Engineering Society, 2016) in each participant's bathroom and bedroom, and the illuminance levels were documented on the printed floor plan. Inside the bathroom, 13 participants' bathrooms' illuminance levels were close to 0 fc, with all the natural and artificial lights being blocked. Two participants' bathrooms had some ambient lights through the blinds of the bathrooms' windows. The two participants mentioned ambient lights transmitted through their bathrooms' windows at night, which was very close to the simulated dark environment during the experiment. Inside the bedroom, four participants used blackout curtains. Their bedrooms were completely dark; eight participants used window blinds, and the illuminance levels of the bedroom ranged from 0.01 to 0.04 fc during the experiment. However, two participants' illuminance levels were around 1–4 fc, depending on the distance from the windows. One participant

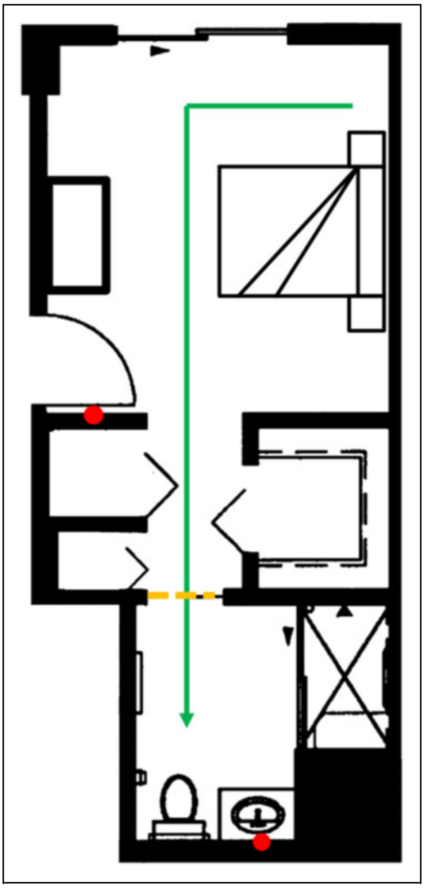

Figure 3. Two participants have the same floor plan as Figure 3, and the figure demonstrates the bedroom, closet, and bathroom of this floor plan. *Note.* The figure shows one participant's furniture layout and the usual nightlights' locations (in red dots). The yellow dot line represents the location of the LED strip lighting system. The green line represents the participant's route from the bed to the bathroom. The floor plan is adopted from the Life Plan Retirement Community website: https://www.oakhammock.org/retirement-community/community-floor-plans.

said she enjoyed ambient lights from outside at night, and she did not install the blinds for the glass doors inside the bedroom. The other participant's apartment is located on the east side, and the blinds cannot block all the natural light in the morning. Since the purpose of the experiment was to examine participants' reactions to the two different lighting scenarios in the real world, the researcher ensured the experiment did not change their daily routines to strengthen the ecological validity of the experiment.

Interview

The semi-structured interview was to understand the three themes, including whether using nightlights or not, whether using nightlight control systems, and participants' evaluations of the LED strip lighting. During the process of the interview, if the participants talked about a specific theme in-depth, the researcher asked more questions during the conversation to understand the participant better, which was defined as a semi-structured interview (DiCicco-Bloom & Crabtree, 2006). For example, the researcher would ask extra questions if the participants showed their nightlight intervention strategies to the researcher, such as the rationales for placing the nightlight in this location. During the interview, the researcher documented the interview's contents in the paper with interview themes listed. The researcher would read the interview's contents to the participants after each theme to make sure the transcripts were correct.

Interview Data Analysis

The interview data analysis followed the steps suggested by Creswell (2009) and Miles (2014). The preliminary work was to organize and prepare data from the written transcripts, the notes on the printed floor plans, and the photos taken during the experiment. Since the sample size was relatively small, two researchers hand-coded the interview contents independently. The researchers read through all the interview transcripts and identified different themes in Excel. The researchers double-checked the interview transcripts to make sure the coded contents reflected the interview transcripts correctly. Later, the two researchers cross-checked the thematic data analysis.

Results

Demographic Information of Participants

Fifteen residents participated in the study. Forty percent ($n = 6$) of the participants were male, and

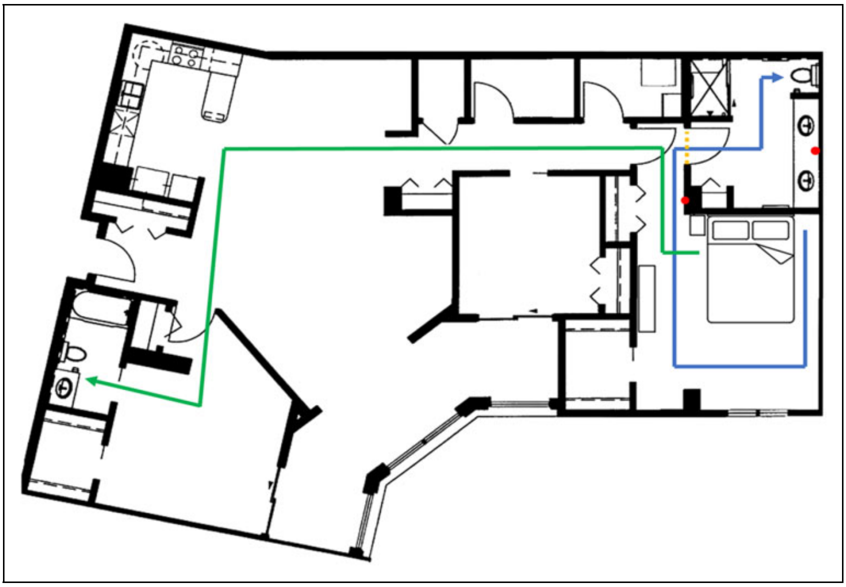

Figure 4. A married couple lives on this floor plan. *Note.* The yellow dot lines represent the location of the LED strip lighting system. The red dots represent the locations of participants' usual nightlights. The floor plan requires a turn from the bedroom to the bathroom. The Husband's route was in green, and the wife's route was in blue. The floor plan is adopted from the Life Plan Retirement Community website: https://www.oakhammock.org/retirement-community/community-floor-plans.

60% ($n = 9$) were female. Twenty percent ($n = 3$) of the participants were aged 85 and older, and 80% ($n = 12$) were between 75 and 84 years old. Thirty-three percent ($n = 5$) of the participants lived alone, and 67% ($n = 10$) lived with their spouses. Falls Efficacy Scale-International (FES-I) evaluated participants' concerns about fall accidents in their daily life, with internal validity (Cronbach's $\alpha = .96$) and test–retest reliability (intraclass correlation coefficient (ICC) = 0.96; Tinetti et al., 1990; Yardley et al., 2005). According to the FES-I questionnaire, 20% ($n = 3$) of the participants were categorized as low concern about fall, 53% ($n = 8$) as moderate concern about fall, and 27% ($n = 4$) as high concern about fall (Table 1).

Movement Behaviors and Anxiety Analysis

The IMU sensors collected participants' movement behaviors, including gait performance, lower limb kinematics, and trunk motion measures. The researchers have discussed participants' movement behaviors under two lighting scenarios in previously published articles (Luo, Lu, Ahrentzen, & Hu, 2021; Luo, Lu, Grimaldi, et al., 2021). The LED strip lighting system improved participants' walking behavior in terms of walking time and walking smoothness. More specifically, when walking from bed to the bathroom in the dark, participants showed an 11% reduction ($p = .014$) in walking time (11.99 s), compared to the usual nightlight condition (13.54s; Luo, Lu, Ahrentzen, & Hu, 2021). And the decrease in walking time was accompanied by a stabler walking smoothness, as demonstrated by the increased values of trunk log-dimensionless jerk (−15.52 vs. −15.13, $p = .002$; Luo, Lu, Ahrentzen, & Hu, 2021) and trunk maximum acceleration (3.48 m/s^2 vs. 3.76 m/s^2, $p = .022$; Luo, Lu, Grimaldi, et al., 2021) under the LED strip lighting system.

The average score of the STAI under the usual nightlight was 22.3 (standard deviation was 3.52), and the average score of the STAI under the LED strip lighting system was 21 (standard deviation was 1.96). Figure 6 displayed the boxplot of the STAI score under two lighting scenarios.

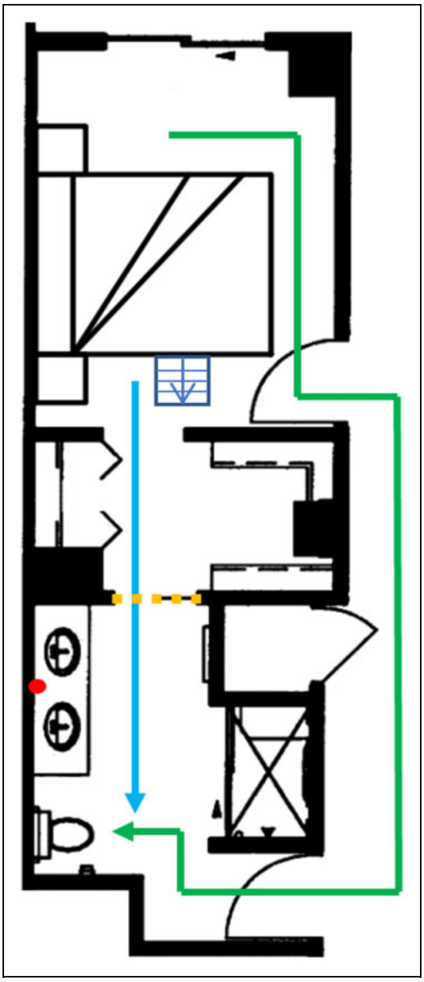

Figure 5. Three participants have the same floor plan as Figure 5, and this figure demonstrates the bedroom, closet, and bathroom of this floor plan. *Note.* The figure shows one married couple's furniture layout and their usual nightlight's location (in red dot). The yellow dot line represents the location of the LED strip lighting system. There was a stair (in blue) for the couple's pets. The space between the stair and the wall was narrow. Due to the narrow space, the husband took the route in green color, walking from the living room to the bathroom. The wife's route was shown in blue color. The floor plan is adopted from the Life Plan Retirement Community website https://www.oakhammock.org/retirement-community/community-floor-plans.

The Wilcoxon Signed-Rank test indicated no significant difference in anxiety between the two lighting scenarios.

Light usage patterns at night. The study found that 80% ($n = 12$) of the participants had plug-in nightlights in their homes, and 20% ($n = 3$) of the participants used either ambient lighting sources or overhead lights instead of using the plug-in nightlights (Table 2). Among the 12 participants who had plug-in nightlights, they installed the nightlights in the bathrooms, bedrooms, living room, kitchens, or laundry (Table 2). Five participants plugged nightlights inside the bathrooms and left the bathroom door slightly open so that they could see the route from bed to the bathroom at night. Four participants installed the nightlights in both the bedroom and bathroom. Three participants installed more than two nightlights, and the areas included the living room, kitchen, laundry, and near the balcony. They wanted to ensure they could see the route if they grabbed something in the kitchen at night. Warm white was the most common nightlight color among the 12 participants. Participants also used amber, green, or colorful LED nightlights. The study also found that six out of the 12 participants used other lighting sources to guide them at night, including indoor ambient lights emitted from electronic devices and outdoor ambient lighting sources emitted from the road lights and moonlight. Two of the participants used overhead lights occasionally. One participant sometimes used a keychain LED flashlight if there was no moonlight outside.

Three participants did not use any plug-in nightlights. One participant just moved in and planned to install a nightlight inside the toilet to light the route to the bathroom. He temporarily used two Google Homes (one was near the bed, and the other was in the bathroom) and a razor charger light (inside the bathroom) as lighting sources. Two participants did not plan to use plug-in nightlights. One participant had a glass door in front of the bedroom, with no blinds for the glass door. The participant said the moonlights and road lights through the glass door can provide enough ambient lighting for her to walk at night. She also rarely went to the bathroom at night. If needed, she turned on the overhead lighting in the bathroom with the dimmest level. The other participant (the only one participant in the study) preferred bright lights at night. She turned on the reading lamp near the bedside, which

Table 1. Demographic Information and Participants' Floor Plans.

Demographic Information Category	Frequency	Percentage
Gender		
Female	9	60
Male	6	40
Age		
75–84	12	80
Above 84	3	20
Live arrangement		
Live alone	5	33
Live with a spouse	10	67
Concerns about falls		
Low	3	20
Moderate	8	53
High	4	27
Turn required from bed to bathroom		
Yes	2	13
No	13	87
Windows inside the bathroom		
Yes	3	20
No	12	80
Owning pets		
Yes	2	13
No	13	87

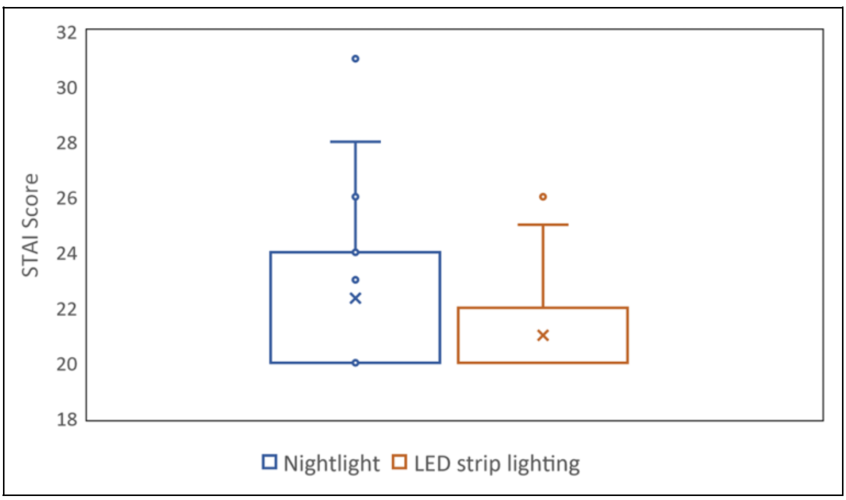

Figure 6. A boxplot of the State-Trait Anxiety Inventory scores under two lighting conditions.

contained compact fluorescent bulbs, and the overhead lights in the bathroom when she went to the bathroom at night. She also carried a fall detector pendant around her neck. The illuminance level in the bathroom ranged from 65 to 100 fc with the overhead lights on.

Nightlights control strategies. The study found that some participants used nightlights control strategies. The most common lighting control strategy included motion, photo, and the photo and motion sensors combination. Participants said the advantage of the sensor-activated lighting control

Table 2. Participants' Nightlights Installation Locations.

Category	Frequency	Percentage
Used plug-in nightlights		
Yes	12	80
No	3	20
Locations of plug-in nightlights		
Bathroom	5	33
Bathroom and bedroom	4	27
Bedroom, living room, kitchen	1	7
Bedroom, bathroom, living room	1	7
Bathroom, laundry room, dining room, kitchen, balcony	1	7
No nightlights	3	20

system was to light the route from bed to bathroom automatically if they needed to go to bathroom at night. But participants also complained that the over-sensitive nightlight control system could disturb sleep; for example, the nightlights could be turned on accidentally when they moved on their beds.

A participant demonstrated her strategy of avoiding direct eye contact with nightlights and overcoming the over-sensitivity of the lighting control system's disturbance to her sleep quality (Figure 7). She plugged two nightlights inside the bathroom, one was on the top of the toilet, and the other was above the sink (see the red dots in Figure 7). She could not see the nightlights when she lay on the bed. When she got up and walked toward the bathroom, the nightlight on top of the toilet could detect her movement and turn on automatically. She could see the route from her bed to the bathroom with the ambient light from outside. The other nightlight above the sink was on automatically when the ambient lighting level was low, providing some lights when she washed her hands.

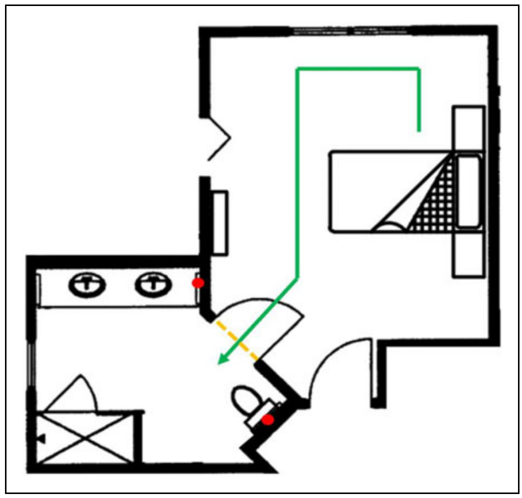

Figure 7. This figure shows the bedroom and the bathroom of the participant's floor plan. *Note.* The green lines represent the participant's route from the bed to the bathroom. The yellow dot lines represent the location of the LED strip lighting system. The red dots represent the locations of the participant's usual nightlights. The floor plan is adopted from the Life Plan Retirement Community website (https://www.oakhammock.org/retirement-community/community-floor-plans).

Participants' evaluation of the LED strip lighting system. Participants' impressions on the LED strip lighting system included positive, mixed feelings, and negative (Table 3). The degree of satisfaction was closely related to their floor plans.

Three participants were satisfied with the LED strip lighting system and agreed that the LED strip lighting outlined the bathroom's doorframe very well. All the three participants' floor plans had a closet area between the bedroom and the bathroom, and the bifold doors of the closet area made the LED strip lighting system an indirect lighting source. The participants' floor plans were very similar to Figure 3.

Nine participants had mixed feelings about the LED strip lighting system. The positive side was that the LED strip lighting system helped them see the bathrooms' doorframes better at night. However, all were concerned that the brightness

Table 3. Participants' Impressions of the LED Strip Lighting System.

	Number of Participants	Comments
Positive evaluation	3	The LED strip lighting outlined the doorframe very well.
Mixed evaluation	9	The LED strip lighting system can be useful if the LED strip lighting system would not disrupt their sleep quality.
Negative evaluation	1	The LED strip lighting was too dim; the participant preferred bright overhead lights to the LED strip lighting system.
Not applicable	2	Participants took different routes to the bathrooms. They could not see the LED strip lighting system when they went to the bathrooms.

of the LED strip lighting could disturb their sleep quality, especially without the motion-activated lighting control system or the inadequate function of the motion-activated sensors.

The positive side was that the LED strip lighting system helped them see the bathrooms' doorframes better at night. However, all were concerned that the brightness of the LED strip lighting could disturb their sleep quality, especially without the motion-activated lighting control system or the inadequate function of the motion-activated sensors.

These participants had similar floor plans' characteristics as Figure 7. The distances from the LED strip lighting system to their bedsides were relatively short. Or some participants placed the bed position as Figure 5. There was no wall or doors to block the LED lighting system partially. Thus, their eyes could see the LED strip lighting system directly when they lay on their beds. Some participants also mentioned ambient outdoor lighting transmitted through their windows inside their bedroom or bathroom. The ambient lighting sources were sufficient for them to navigate in the dark. In addition, the mixed feeling to the LED strip lighting system is also relevant to whether participants had already installed nightlights at home. The participants thought that either the LED strip lighting system was similar to theirs or their nightlights worked better.

Only one participant had negative comments about the LED strip lighting system, and she preferred her bright overhead light and reading lamp to the LED strip lighting system. The one participant as mentioned earlier (Please refer to the subsection of *Light Usage Patterns at Night*) liked bright light at night and commented that the LED strip lighting system was too dim for her. That is possibly related to her high concern about fall accidents and her vision impairment.

Two participants commented that the LED strip lighting system did not apply to them. One participant managed to make minimum inferences to his spouse's sleep when they went to the bathroom at night by taking the route through the living room to the guest room bathroom (see green lines in Figure 4). This participant used the combination of his nightlights inside the bedroom and the overhead lights inside the living room. The other participant detoured the living room to the bathroom due to the narrow space between the pet stair and the wall (see green lines in Figure 5).

Recommendations for redesign. Participants gave recommendations to improve the design of the LED lighting system, which included providing lighting sources inside the bathrooms, reducing the length of the LED strip lighting, changing the LED strip lighting color to amber color, and adding an effective motion-activated nightlight control system.

...providing lighting sources inside the bathrooms, reducing the length of the LED strip lighting, changing the LED strip lighting color to amber color, and adding an effective motion-activated nightlight control system.

In the walking trials, the LED lighting system was attached to one side of the bathroom door.

Four participants suggested that providing lighting sources inside their bathrooms would be helpful for them to navigate safely at night. There were no windows inside the bathroom in the floor plans, and their bathrooms were completely dark; they could not see the route from the bathroom to the bed. They suggested it would be helpful to install the LED strip lighting on both sides of the bathroom's doorframe. Two participants were also concerned that their eyes sensitivity would decrease as they aged and suggested adding lighting sources inside the bathroom to provide visual guidance.

One participant did not think the whole length of the LED lighting was necessary since she only needed a small amount of lighting to help her see the direction of the bathroom. She suggested attaching a small length of LED strip lighting on her bathroom's doorknob.

Two participants had pilot experiences and suggested using red (or amber) color lighting to help people adapt to the dark environment better. They explained that white color lighting could bleach out the chemical of the eyes and make the eyes less sensitive to dark adaptation.

Observations of Participants' Movement Behaviors

The study observed participants' behaviors while walking in the simulated dark environment. The study found that the layout of the furniture, the nightlight control systems, whether the bathroom's door is kept slightly open, and owning pets at home can change participants' movement behaviors.

Participants walked slower or stopped for a few seconds when they encountered a piece of furniture in the dark. The furniture included the bed, cabinet, dresser, and bookshelf. Some participants reached out to a piece of furniture for support, such as the vertical column of the four-poster bed. It was possible that reaching out to the furniture can increase a sense of safety in the dark, particularly while navigating along a narrow pathway. As mentioned earlier, some participants kept the bathroom door slightly open to see the route from the bed to the bathroom. However, some participants kept the bathroom door closed so that they stopped for a few seconds to find the doorknob to open the bathroom doors.

Although participants mentioned that oversensitive of the nightlight control system disturbed their sleep at night, one participant said she had to wait for the nightlight to turn on before walking because her nightlight motion detector delayed a few seconds. Her waiting for the nightlights to turn on was also observed in the study.

The study also found that owning pets affected older adults' movement behaviors. The other married couple had pets at home, and they placed a stair near their bed so that the pets could climb to the bed easily (Figure 5). However, the space between the stairs for the pets and the walls was too narrow to walk at night. The husband was aware of the safety issues, and he took another route to the bathroom, walking from the living room to the bathroom with a staff (Figure 5).

Discussion

The field experiment provides a strong ecological validity (Andrade, 2018) by examining older adults' movement behaviors and anxiety states in their real residential settings. The field experiment combined objective measurements of older adults' gait characteristics, subjective measurements of their anxiety states while walking in the dark, and an in-depth interview to understand older adults' nightlight usage habits and their acceptance to the LED strip lighting intervention. The combination of the research methods, including the qualitative and quantitative analysis, helped the researchers to have an expanded understanding of older adults' nightlight usage and their acceptance of the LED strip lighting (Creswell, 2009).

One innovation was to use wearable sensors to measure older adults' gait characteristics in their residential settings, compared to the existing literature (Figueiro et al., 2012; Figueiro et al., 2011; Thölking et al., 2020). With the minimum interruptions to older adults' everyday routines, the wearable sensors can reflect older adults' gait performance in a dark environment.

Previous lab studies (Figueiro et al., 2012; Figueiro et al., 2011) indicated that LED strip lighting was beneficial in a uniform floor plan.

The real-world field experiment brings new insights by examining the LED strip lighting's effects on older adults' movement behaviors under different floor plans. The 11 types of floor plans in the field study almost represented all the types of bedroom and bathroom layouts in the independent living facility. The study was able to receive different feedback from the older adults due to the different bedroom-to-bathroom layouts. For example, the LED strip lighting was able to provide indirect ambient lighting for certain bedroom-to-bathroom layout (Figure 3), where a closet exists between the bedroom and bathroom, and the LED strip lighting received positive evaluations. However, the LED strip lighting can disrupt older adults' sleep quality if the LED strip lighting was installed on certain bedroom-to-bathroom layout (Figure 7), where the distance from the bedroom to the bathroom is very short. Such new insights might not be discovered if we tested the LED strip lighting in a uniform lab environment.

Although the field experiment cannot control all the factors as a lab-setting experiment, the combination of the interview and gait performance results can help explore the LED strip lighting effects on older adults' movement behaviors in the dark (Creswell, 2009). The gait characteristics analysis indicated that older adults spent 11% reduction in the walking time and demonstrated a stabler walking pattern in the LED strip lighting system compared to their usual nightlights conditions (Luo, Lu, Ahrentzen, & Hu, 2021; Luo, Lu, Grimaldi, et al., 2021). But the interview results indicated that the design of the LED strip lighting system could be improved. For example, some participants already had spent extra effort to compare nightlight installation locations by themselves. Thus, they knew better nightlight installation locations to help them see at night while the nightlights won't disturb their sleep. The study finds out that visual health condition affects the acceptance of the LED strip lighting in the interview. For example, one resident with several eye diseases is concerned about fall accidents and preferred bright overhead lights to the LED strip lighting. The combination of the interview and the objective gait characteristic measurements suggested the lab-setting effective LED strip lighting system should be redesigned to satisfy older adults' needs in their home settings.

There are multiple limitations that need to be pointed out. The current study did not find the statistical difference of the anxiety states between the two lighting scenarios, but Thölking and colleagues' study (Thölking et al., 2020) indicated that nightlights were beneficial to lower participants' fear of falls and improving sleep quality, with an average time of 118 days installing the Gight™. One of the possible explanations is that having the same STAI test in a short time might not reflect older adults' true anxiety levels while walking in the dark environment. Using the same testing (STAI questionnaire) in a short time during the experimental procedure can be an internal validity threat to the experiment (Campbell et al., 1963; Creswell, 2009). Another possible explanation for the no statistical difference in the anxiety states (STAI) between the two lighting scenarios was that the participants were not sleepy during the study. The study wanted to make minimum inferences on their daily lives, like avoiding collecting movement data during participants' sleep time. Thus, the STAI might not reflect participants' actual anxiety when they got up and walked to the bathroom at nighttime although the movement analysis indicated that the LED strip lighting system was helpful to their smooth movement.

The small sample size was another limitation. Since the study was conducted at home, people can be hesitant to participate due to privacy concerns. After conducting several experiments in different residents' homes, more residents are willing to participate. However, the COVID-19 affected the whole research community negatively in early 2020 (Subramanya et al., 2020). Our study was also severely interrupted by the COVID-19. The reported samples were collected just before the pandemic outbreak, and due to the nature of our experimental protocol and the vulnerability of the targeted population, we did not continue the data collection.

The field experiment provided insights to future research directions. The current study recruited participants were from the independent living facility of the Life Plan Retirement Community, which indicated they were in a relatively healthy status. It would be beneficial to conduct a study in the future with different sample characteristics, such as participants in different geographical areas, with different visual capacities. The research findings from a diversified sample characteristics can be generalized to a broader aging population.

Conclusions

Although the LED strip lighting system in the lab setting indicates that visual cues can help older adults walk safely in the dark, details of the placement of the nightlights should be addressed when applying the LED strip lighting system in home settings.

The field study found that factors such as the layout of the furniture, floor plan, living arrangement, visual capabilities, owning pets, ambient lighting sources, concerns about falls, concerns about sleep quality, lighting control system, and whether owning nightlights previously can determine the older adults' acceptance of the LED strip lighting system. The layout of the floor plan and the distance from the bedside to the bathroom can be the most prominent factors to explain the differences.

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The study also found that designers should emphasize the nightlights control system. The nightlight control system can be crucial to older adults' sleep quality and safe movement during the night. Participants kept mentioning that the motion detectors should work adequately. Oversensitive motion-activated sensors can turn on the nightlights accidentally while older adults toss on the beds, which disrupts sleep quality. In contrast, the motion-activated sensors' delay in turning on nightlights can make participants hesitant to walk before the nightlight is on. Thus, the lighting control system can be an essential design factor when installing nightlights for older adults.

The Illuminating Engineering Society (2020) provides general nightlight guidelines for older adults and people with visual impairments, including the height of the nightlight locations and the color of the nightlights. However, they might also need to add other factors in the future recommendations, such as combining with the existing floor plans and furniture layouts of the older adults, ambient lighting whether sufficient for aging eyes.

Implications for Practice

- Providing appropriate visual cues at night was beneficial to older adults' safe movement.
- Although the destination-based LED strip lighting system was helpful in fall prevention in the lab setting, designers should consider older adults' lifestyles, floor plans, furniture layout, ambient lighting sources, and sleep quality before placing the LED strip lighting system in the actual home setting.
- The interview reveals that some older adults did research about the nightlights, and they were concerned about the effectiveness of the nightlight control strategy.

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