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RESEARCH ARTICLE

An Investigation of Light Spectrum and Intensity on Depression among Older Adults

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Abstract

The impact of lighting in buildings on managing behavioural and psychological symptoms, particularly in older adults, is significant as it affects visual and circadian systems. With age-related changes in eyes and circadian system, specialized lighting design is crucial to promote mood and overall well-being in older people. This study aimed to assess the effects of two types of ambient lighting interventions on depression in older adults. Both interventions involved creating a direct/indirect ambient illumination with high illuminance level (500 lux) in the morning (8:00-12:00), followed by gradual dimming throughout the day until reaching 100 lux in the evening (after 20:00). Depression levels were measured before, during, and after the lighting interventions using the Geriatric Depression Scale. The results showed a significant decrease in depression after exposure to both lighting conditions, with greater reduction observed in the L2 intervention. These findings highlight the positive effects of incorporating varying illumination and spectrum in the ambient lighting quality of residential buildings. Considering that older adults spend most of their time indoors, designing ambient lighting with varying intensity and tuning spectrum throughout the day could be a promising therapeutic approach to reduce depression, create an environment that promotes mental health, and improve the overall quality of life in older adults.

Introduction

Depression is a prevalent symptom in older adults, with estimated prevalence rates ranging from 8.2% to 63.0% globally [1-3]. Depression can bring about psychological distress, functional impairment, and, consequently, poorer overall health outcomes [4-6]. In older adults, depression is associated with cognitive impairment and could approximately double the risk of dementia [7-9]. Moreover, these depressive symptoms could place additional stress on caregivers in both institutional and home settings [10,11].

Lighting is a particularly important element within the living environment that enables more comfortable living. Proper lighting improves older adults' visual performance and prevents falls [12-14]. Light serves as a primary stimulus that regulates circadian rhythms, seasonal cycles, and neuroendocrine responses in various living beings, including humans, on Earth [15-17]. Extensive research has demonstrated that impaired functioning of the circadian system in humans has adverse effects on their health and overall well-being [18-20] and increases the risk of metabolic syndromes, cardiovascular diseases [21], and cancer

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[22], as well as mental illnesses such as depression [23] and anxiety [24]. Hence, researchers argue that light with the correct characteristics could be as effective as medication in the treatment of depression if it is employed at the right time and with sufficient duration [25-27]. Due to age-related changes in the eyes, such as lens-yellowing, lens thickening, and senile meiosis, older adults require higher illuminance levels, particularly short wavelength light, for visual and circadian effects compared to younger age groups [28]. These changes lead to a decline in the amount and characteristics of the light that reaches the retina. Research has demonstrated that the amount of light received by the retina of a 20-year-old is three times higher than that of a 60-year-old and six times higher than that of an 80-year-old individual [29]. In practice, older adults are not exposed to sufficient amount of illumination [30]. Studies reported poor lighting conditions in senior living communities [31-33]. Furthermore, a significant number of older adults do not spend adequate time outdoors where they can be exposed to high illuminance levels from sunlight. Limited exposure to appropriate lighting is a major contributing factor to depression and problematic behaviours in geriatric populations, which in turn adds additional stress for caregivers [34].

There is a positive impact of ambient overhead bright blue light on enhancing mood and treating depression among older adults [35,36]. Researchers found a significant inverse association between ambient illuminance levels exceeding 400 lux during daytime and depression scores among older adults [37]. While daytime ambient bright light is known to have beneficial impacts, exposure to high illuminance levels during night-time has been associated with an increased risk of depression among older adults [38], possibly due to circadian phase delay and impaired sleep quality. In addition to the illuminance levels, the spectrum (or CCT) of the lighting plays a role and certain behavioural and circadian effects that are obtained with bluish cool light (CCT of 6500 K or higher) are not found in yellowish warm light (CCT of 2700 K or lower) [39-41] found that exposure to 200 lux blue light with a CCT of 12000 K in the morning significantly improved depression symptoms among older adults with Alzheimer's disease. This effect was not found in yellow light with a CCT of 2400 K at 200 lux.

Presumably, a whole-day ambient lighting design with varying illuminance levels and spectrum (or CCT) could effectively manage mood and depressive symptoms in older adults. This study evaluates the impact of applying two whole-day ambient lighting interventions in senior living communities on depression in older adults who reside in the community. These lighting interventions are designed specifically to meet visual and circadian needs of older adults and provide a range of illuminance levels, and/or CCTs that change throughout the day.

Methods

Participants

Recruitment for the study was conducted in April 2019 to October 2020 through distributing flyers to the residents of two senior living communities in Saint Louis, MO. A total of 23 individuals signed up for the study. However, after screening, nine individuals were excluded after screening. Exclusion criteria included evidence of moderate to major dementia based on the Montreal Cognitive Assessment (MoCA) test (score of 25 or lower), blindness, current use of light therapy, spending most of their daily time (more than 5 hours) outside their private residential units, or planned upcoming travel out of the time zone during the study participation period. Informed consent was obtained from 14 older adults (11 female) with ages ranging from 65 to 91 years and a mean age of 73.2 years (SD 7.9).

Lighting intervention

Lighting interventions included two whole-day lighting schemes with varying illuminance levels and/or CCTs. Both lighting schemes were designed based on available research to meet circadian lighting needs of older adults. Although no previous study examined the impact of a whole-day lighting intervention on depression in older adults, what we perceived from prior literature indicates that an optimum lighting solution for circadian entrainment should provide:

- High levels of bright blue illuminance (high intensity + high CCT (or blue-enriched white light)) early in the morning to phase advance the circadian clock.
- Medium to high levels of illuminance (medium to high intensity + medium CCT (neutral white light)) in the afternoon to increase alertness without exerting substantial phase shifting effects on the circadian clock

- Dimmed illumination (low intensity + low CCT (yellowish white light)) in the evening to avoid disruption of circadian rhythms and unwanted phase delay.

Given these primary principals, both lighting interventions designed for this study provided a high illuminance level (500 lux, corneal) in the morning (8:00-12:00) and then the illuminance level was reduced gradually towards the evening and reached 100 lux (corneal) after 20:00. One Lighting scheme (L1) delivered a constant CCT of 2700K which is the most common CCT in the residential environment. In the other lighting scheme (L2), the CCT was changing in a range of 6500 K-2700 K from morning towards evening. Table 1 shows illuminance levels and CCT of each intervention throughout the day. Studies evaluating the effects of CCT and spectrum on depressive symptoms report inconsistent results [42]; hence, some researchers argue that, perhaps, the color of light is not a significantly effective factor in circadian lighting design [43]. We designed L2 to examine if adding tuning color quality to the ambient illumination with varying intensity would provide any extra benefits with regards to depression levels in older adults.

Lighting interventions were implemented by positioning 4 to 6 four-foot linear tunable white light fixtures (FloatPlane by Ledalite, Suspended, LED) in the living rooms of the participants at a height of 7 feet. The light fixtures were set up on Manfrotto stands and provided a direct/indirect lighting distribution (75% up-25% down), offering a wide range of Correlated Color Temperatures (CCTs) from 2700 K to 6500 K. The placement of the light fixtures was arranged in an L-shape or U-shape geometry around the main seating spot, maximizing corneal light levels in most gazing directions through indirect light reflection from ceilings and walls. This arrangement helped ensure uniformity of lighting distribution as the light was transmitted and reflected from various directions to/around the designated spot.

Study design

A counterbalanced crossover study was developed to assess changes in depression levels among participants before, during, and after the implementation of lighting interventions, utilizing the Geriatric Depression Scale (GDS).

In the week preceding the lighting interventions, a pre-test assessment was conducted to establish baseline depression levels among participants in their usual lighting condition. Subsequently, lighting interventions were implemented in the participants' homes and in-home lighting assessments were performed. Each lighting intervention was experienced for nine days, and depression levels were evaluated on the final day of each intervention. The 14 participants were randomly divided into two groups (Group A and Group B) in a counterbalanced study design, experiencing different orders of lighting interventions, Group A: Baseline1-L1-L2-Baseline2 and Group B: Baseline1-L2-L1-Baseline2. Following the intervention sessions, a two-week washout period was implemented, during which the experimental lights were removed, and participants returned to their original lighting conditions in the living room. A post-intervention depression assessment was conducted on the last day of the washout period to determine if participants returned to baseline depression levels observed during the pre-test assessment.

Measure

Depression in participants was measured using the Geriatric Depression Scale (GDS), a widely used 30-item self-report assessment to identify depression in older adults. The GDS is known for its high internal consistency (Cronbach's alpha of 0.85) and high test-retest coefficient reliability (0.83) [44]. The GDS, a self-report questionnaire, utilizes a yes/no format, making it simple to administer, and primarily addresses patients' worries and their perception of their quality of life, while excluding

Table 1: Whole-day lighting interventions.

	Intervention 1 (L1)		Intervention 2 (L2)	
Time	**Illuminance levels (lux)***	**CCT (°K)**	**Illuminance levels (lux)***	**CCT (°K)**
8:00-12:00	500	2700	500	6500
12:00-16:00	400	2700	400	4500
16:00-18:00	300	2700	300	3500
18:00-20:00	200	2700	200	3000
20:00-24:00	100	2700	100	2700

somatic complaints commonly found in older adults. Despite lacking items related to agitated or psychotic behaviour, the GDS is designed to assess the cognitive aspect of depression (thought content) and is strongly correlated with the Beck Depression Inventory [45].

Results

Sample characteristics

The mean age in group A was 76 (SD 7.57) and group B was 73 (SD 8.98) with no significant difference between groups (p = 0.39). The majority were female (78.5%), white (92.8%), and had been living in their current dwelling unit for more than 12 months (85.7%). As shown in table 2, the demographic profiles of the participants in both groups were similar.

Effects of Whole-day Ambient Lighting Schemes on Depression: The patterns of the depression scores across the study are illustrated in figure 1. The general pattern is similar for the two groups; namely, depressions scores decrease with the L1 intervention, decrease even more with the L2 intervention, and start returning to baseline levels after the intervention has been discontinued. These general trends were assessed with an independent t-test statistical analysis to determine the effectiveness of the

Table 2: Sample characteristics (n = 14).

Variable	Group A (n = 7)		Group B (n = 7)		p
	n	%	n	%	
Gender					0.55
Female	5	71.4%	6	85.7%	
Male	2	28.6%	1	14.9%	
Race					0.34
White	7	100%	6	85.7%	
African-American	0	0%	1	14.9%	
Asian	0	0%	0	0%	
Others	0	0%	0	0%	
In Current Unit					0.55
> 12 months	6	85.7%	5	71.4%	
6-12 months	1	14.9%	2	28.6%	
< 6 months	0	0%	0	0%	
	Mean	**SD**	**Mean**	**SD**	p
Age (year)	76	7.57	73	8.98	0.39
Daily hours in unit	6.7	0.95	7	0.82	0.63

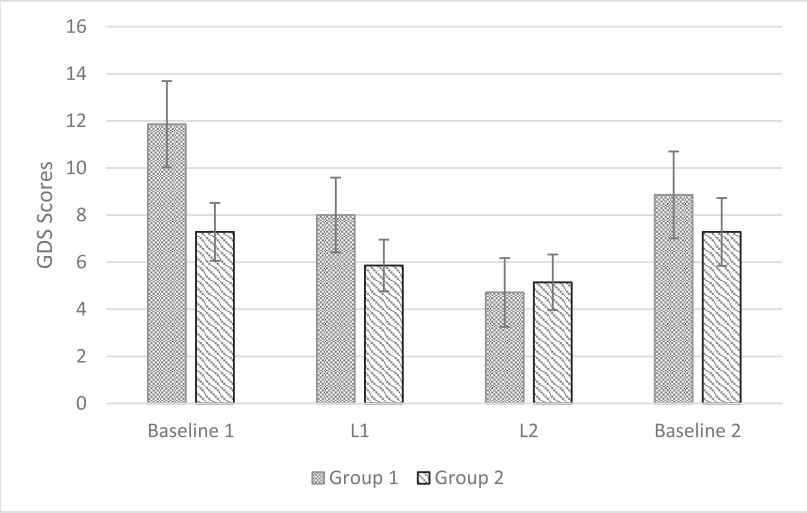

Figure 1 Effectiveness of the L1 and L2 interventions on depression.

experimental whole-day lighting interventions on depression among older adults. Data were managed and analysed using IBM SPSS 22.0 statistical software.

As indicated in table 3, exposure to L1 intervention for 9 days decreased the mean GDS score significantly by 3.86 points in group A ($t = 3.59$, $p = 0.04$) and 1.43 points in group B ($t = 3.59$, $p = 0.04$) compared to baseline 1 measurements. L2 intervention provided even more reduction in the mean GDS score in both groups. Following the L2 intervention, mean GDS score of group A significantly dropped by 7.15 points from the baseline 1 ($t = 3.58$, $p = 0.01$) and by 3.29 from the L1 ($t = 2.8$, $p = 0.03$). In group B, a significant reduction was observed in the mean GDS score after L2 intervention compared to the baseline 1 ($t = 2.94$, $p = 0.03$); nevertheless, the difference between L1 and L2 was not statistically significant ($t = 1.53$, $p = 0.18$). No significant difference was found in the mean GDS score in baseline 1 and baseline 2 in both groups (group A ($t = 1.6$, $p = 0.15$), group B ($t = -0.44$, $p = 0.67$)), nor between L1 and Baseline 2 (group A ($t = -1.03$, $p = 0.34$), group B ($t = -1.92$, $p = 0.01$). However, the mean GDS score in Baseline 2 was significantly higher than L2 in both group A ($t = -5.61$, $p = 0.001$) and group B ($t = -3.49$, $p = 0.01$) (Table 4).

An independent t-test showed no significant difference in the mean GDS score between groups in baseline 1 ($t = 2.12$, $p = 0.05$), L1 ($t = 1.11$, $p = 0.29$) L2 ($t = -0.08$, $p = 0.94$), and baseline 2 ($t = 0.56$, $p = 0.58$). Although it was statistically insignificant, Baseline 1 measurements revealed that the mean GDS score in group A was 4.71 points higher than group B. After 9 days of exposure to the L1 and L2 interventions, we observed more reduction from the baseline 1 in mean depression scores in group A compared to group B (Table 5).

Discussion

In this study, a counterbalanced crossover design was used to explore the effects of two different ambient lighting schemes (L1 and L2) on depression levels in older adults living in senior living communities. As anticipated, after 9 days of exposure to both lighting interventions, there was a significant decrease in mean depression scores as assessed by the GDS. The lighting interventions provided a high illuminance of 500 lux in the morning (8:00-12:00), gradually decreasing to 100 lux in the evening (after 20:00). Interestingly, even though L1 intervention maintained a constant CCT of 2700K, there was a noteworthy reduction in depression levels in participants. Group A showed a 33% decrease in mean depression scores, while group B showed a 20% decrease after exposure

Table 3: Effectiveness of the L1 and l2 interventions on depression ($n = 14$).

Variable	Baseline 1		L1		L2		Baseline 2	
Depression (GDS)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group A	11.86	4.85	8.00	4.20	4.71	3.86	8.86	4.88
Group B	7.29	3.25	5.86	2.91	5.14	3.13	7.29	3.82

Table 4: Effectiveness of the L1 and L2 interventions on depression within a group.

Variable		Baseline1 & L1		Baseline 1 & L2		L1 & L2		L1 & Baseline 2		L2 & Baseline 2		Baseline 1 & Baseline 2	
Depression (GDS)	n, df, σ^2	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
Group A	7, 6, 23.48	2.51	0.05	3.58	0.01	2.81	0.03	1.03	0.34	5.62	0.00	1.64	0.15
Group B	7, 6, 11.14	3.58	0.01	2.94	0.03	1.53	0.18	1.92	0.10	3.49	0.01	0.44	0.67

Table 5: Effectiveness of the L1 and L2 interventions on depression between groups ($n = 14$, df = 12).

Variable	Group A		Group B					
Depression (GDS)	**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**	**t**	***p***	**σ^2**
Baseline 1	11.86	4.85	7.14	3.25	4.71	2.12	0.06	17.31
L1	8.00	4.20	5.86	2.91	2.14	1.11	0.29	13.07
L2	4.71	3.86	4.86	3.13	-0.14	-0.08	0.94	12.36
Baseline 2	8.86	4.88	7.57	3.82	1.29	0.56	0.58	18.21

to L1 intervention. These results align with recent research that has shown the positive effects of receiving high intensity morning light on depression and mood, regardless of the color and spectrum of the light [46-50]. Nevertheless, it is worth noting that previous studies have typically exposed participants to lighting interventions for shorter durations of 30 to 120 minutes, and none have examined the effects of whole-day lighting interventions. This highlights the importance of illuminance level as a significant light characteristic that can impact mood in older adults.

The spectrum of light was a significant feature investigated in this study. During the L2 intervention, we introduced varying illuminance levels to provide bright cool light in the morning and dimmed warm light in the evening, while also tuning the spectrum quality of the ambient illumination. The results showed that L2 intervention led to a reduction in mean depression scores by 60% in group A and 30% in group B, surpassing the effects of L1 intervention in both groups. This supports the notion that incorporating tuning spectrum in environmental lighting can offer additional benefits in reducing depression and improving mood and well-being in older adults, indicating that the color of light also plays a crucial role.

No previous study applied a similar whole day ambient illumination in dwelling units of healthy older adults. Nonetheless, these results are aligned with those from a few other studies that reported the beneficial effects of blue light exposure on enhancing mood in older adults with dementia [51-54]. Anecdotally, our participants responded positively to the experimental lighting interventions, with a majority expressing a preference for L2 intervention over L1, as they felt it closely resembled natural lighting, particularly in the morning.

Although not statistically significant, we observed lower mean depression scores in baseline 2 compared to baseline 1 in both groups, which may suggest lasting effects of the interventions on participants. However, further research is needed to determine the duration of such effects in older adults. Additionally, our results showed no significant effects of the order of exposure, as the difference in mean depression scores between L1 and L2 interventions did not differ significantly between the groups.

Implementing a whole-day lighting scheme with tuning spectrum and intensity proved to be an effective design approach for reducing depression and improving mood and well-being in older adults. However, despite the well-established effects of light on health in older adults, lighting is often overlooked as a design priority among architects, particularly in residential units. In many residential units, ceiling/wall luminaires are only designed for kitchen and bathrooms, and no permanent lighting system is considered for living rooms and bedrooms. Instead, architects often rely on day lighting and floor/table lamps provided by residents to illuminate living rooms. However, these lighting systems may not create a uniform lighting distribution, resulting in poor lighting conditions in living rooms, which are where older adults spend most of their active time when at home. On the other hand, the availability of indoor daylight may vary depending on factors such as weather conditions, climate, and types of day lighting systems. As a result, many living units of older adults may have inadequate and dim lighting conditions [55].

Hence, integrating an ambient illumination system with adjustable intensity and spectrum could serve as a promising design solution to create a healing living environment and enhance mood and overall quality of life in older adults. This can be achieved by incorporating proper day lighting systems along with tunable white luminaires mounted on ceilings or walls, providing both direct and indirect lighting distribution. Direct lighting distribution caters to visual tasks, while indirect distribution promotes the biological effects of light. To ensure optimal results, these tunable white luminaires should be equipped with smart lighting and day lighting control systems, allowing for adjustments in light levels and Correlated Color Temperature (CCT) throughout the day to meet the unique needs of each individual. This ethical approach of exposing older adults to therapeutic lighting can help establish a healthy living environment. Notably, in regions with cold or cloudy climates where natural light benefits may be limited, ceiling luminaires play a particularly crucial role for older adults.

This field study of course has limitations. One significant limitation is the small sample size, which may restrict the generalizability of the findings. Additionally, there was no formal observation to monitor the actual duration of participants' exposure to the study interventions. Furthermore, the absence of a formal control group, such as having experimental luminaires that simulate conventional lighting conditions only, may also impact the study's

results. In future research endeavours, it would be beneficial to increase the sample size and diversity of participants, extend the duration of exposure to the whole-day lighting interventions, assess the long-term effects of these interventions, and compare the results to a control group to obtain more robust and comprehensive findings.

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