LIGHTING AND WOMEN'S PERCEPTION OF SAFETY AT NIGHT IN URBAN AREAS

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ABSTRACT
This study investigates the impact of various lighting conditions on perceived safety in urban environments, with a specific focus on bollard and pole lighting combined with different color temperatures. The main question is: which lighting characteristics most effectively enhance women's sense of safety at night? Given that women's participation in outdoor activities significantly declines after dark—negatively affecting their health and well-being—we employed immersive virtual reality simulations to evaluate perceived safety across five distinct lighting scenarios. Fifty female volunteers participated in this study and our findings reveal that scenarios incorporating bollard lighting significantly enhance perceived safety compared to those with only pole lighting. However, contrary to some previous research, our study found that color temperature did not significantly impact perceived safety scores. Additionally, we tested the interaction effect between lighting height and color temperature and found no significant interaction, indicating that the influence of lighting height on perceived safety is independent of color temperature. This insight can help to improve nighttime walkability and women's health by creating a safer environment to have nighttime activities. Our research contributes to the body of knowledge on urban lighting design, offering valuable guidelines for planners, designers, and policymakers to enhance urban safety and livability.

Keywords
Women's Perceived Safety, Lighting Height, Correlated Color Temperature, Virtual Reality

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1 INTRODUCTION

Lighting plays a crucial role in creating a sense of safety and security in public spaces, including streets and sidewalks (Boyce et al., 2000). Effective lighting not only enhances our ability to see but also positively influences our perception of the environment and our sense of safety while navigating through it (Dastgheib, 2018). This research focuses on the importance of perceived safety at night for women. A higher sense of safety can directly contribute to the livability of a city because when people feel safe walking at night, they are more likely to engage in evening activities, thereby enhancing vibrancy and social interaction within the community. The livability of a city can also significantly influence its economy by providing more opportunities for people to remain active during nighttime hours, thereby improving local businesses, fostering nightlife, and enhancing overall economic vitality. By ensuring that urban environments are well-lit and perceived as safe, cities can promote a more active and economically prosperous community.

Safety also significantly impacts the walkability of an area. When a place is perceived as safe, more people use the space and walk, leading to increased foot traffic and a more vibrant street life. A more walkable environment has numerous benefits, including improved public health, reduced traffic congestion, and lower pollution levels (Baobeid & Al-Ghamdi, 2021). Therefore, safety is not just about preventing crime but also about creating an inviting and comfortable environment for pedestrians, which is essential for the overall walkability and quality of life in urban areas.

Participation in nighttime activities drops significantly after dark (Boomsma and Steg, 2014), and one of the most crucial factors contributing to this decline is safety (Bromley et al., 200). Research shows that women's social activities in particular decrease drastically after dark because they feel less safe compared to men (Blöbaum & Hunecke, 2005; Loewen et al., 1993; Boomsma and Steg, 2014). On average, college women are three times more fearful of being victims of sexual violence at night on their campus compared to college men (Fisher & Sloan, 2003). As a result, women often avoid places and situations they perceive as unsafe, leading to a restriction in their daily activities (Keane, 1998; Valentine, 1989; Mitra and Bardhan, 2017), which can impact their ability to participate in physical activities such as walking outdoors (Valentine, 1989).

Safety at night can be influenced by several historical, social, and individual factors, however, one of the most critical is environmental design (Yu, 2015). The design of a space can significantly impact the level of perceived safety, with lighting playing a paramount role (Mushtaha et al., 2022; Dubey at al., 2025). Streets and public spaces should be designed and maintained with sufficient lighting to enhance visibility and promote a greater sense of safety for women and gender minorities during nighttime (Messa et al., 2025). Effective lighting design can improve urban spaces by enhancing visibility and reducing areas where potential threats might hide. It is also important to distinguish between actual safety and perceived safety. Actual safety refers to the measurable crime rate in a given area, while perceived safety is defined as “a person’s immediate sense of security” (Haans et al. 2012; Blöbaum & Hunecke, 2005; Park et al. 2008). This research investigation focuses solely on perceived safety.

The effect of color temperature on perceived safety is a topic of debate within the lighting research community. Maciejewski (2018) found that participants preferred environments characterized by cooler (bluish) light with higher color temperature. Similarly, Bullough and Skinner (2015) found that white light appears brighter and consequently safer than yellowish light. Other researchers have reached comparable conclusions and generally consider white light a better source for enhancing perceived safety (Boyce et al., 2000; Peña-García et al., 2015; Knight, 2010). While Maciejewski, Bullough, and others concluded that higher color temperature is directly correlated with higher perceived safety, other studies show the opposite. Research by Saad et al (2021) found that uniformity and warm color light are important factors in the perception of safety. Similarly, Liu et al (2022) concluded that people feel safer when nighttime light is warm and uniform. This lack of consensus on the ideal color temperatures for perceived safety highlights the need for further research in this area. Table 1 presents a summary of existing literature on perceived safety and correlated color temperature.

Table 4: Summary of previous research on perceived safety in relation to correlated color temperature (CCT), highlighting contrasting findings on the effects of warm and cold lighting.

Perceived Safety by Correlated Color Temperature (CCT)	Cited Literature	Key Findings
Warm Color Temperature	Saad et al., 2021 Liu et al., 2022	Warm and uniform light improve perceived safety.
Cold Color Temperature	Maciejewski, 2018 Bullough and Skinner, 2015 Boyce et al., 2000 Peña-García et al., 2015 Knight, 2010	White light appears brighter and safer.

Meanwhile, street lighting is also a critical aspect in promoting safety in urban areas. Different patterns of light distribution can be created by varying the spacing and height of lamp posts (Fotios et al., 2019). The height of street lighting, which ranges from 8 to 50 feet, plays a crucial role in shaping our perception of an area and, consequently, our perceived safety (Dastgheib, 2018). Scorpio et al (2020) found that the height of the light fixture significantly impacts visual performance and, therefore, perceived safety. While pole lighting is the most common method used to illuminate streets, growing evidence suggests that bollard lighting can significantly improve perceived safety in pedestrian areas (Vogel & Pettinari, 2002; Bullough & Skinner, 2015).

Several studies have focused on lower (approximately 3 feet high) lighting and perceived safety in illuminated exterior environments. Vogel and Pettinari (2002) concluded that low-pole or bollard lighting creates “people-scaled illumination” in dark corners around transit stations. Paskovic (2012) claimed that bollard lighting in pedestrian areas accentuates “an inviting public realm.” In another study, Bullough and Skinner (2015) found that the use of bollard lighting led to a significant increase in the perception of safety compared to the traditional pole lighting on an average Street. Additionally, Bullough and Skinner did a study at Rensselaer Polytechnic Institute that examined the relationship between bollard-level lighting and safety at crosswalks, focusing on wayfinding and navigation aspects. Paskovic (2012) also reported that bollard lighting in pedestrian areas promotes continuous movement, leading to an inviting public realm. Therefore, while pole lighting is the most common method of illuminating streets, growing evidence suggests that bollard lighting can significantly enhance perceived safety. However, most of these studies primarily focus on pedestrian safety from vehicles, highlighting the need to investigate the impact of bollard lighting on pedestrian safety. While these studies often consider bollard lighting as an alternative to pole lighting, we argue that the two should be viewed as complementary elements. While pole lighting offers broader coverage and better uniformity, bollard lighting enhances facial recognition and reinforces the intentionality of design at the human scale. Given the importance of lighting height on perceived safety, this study aimed to compare the impact of bollard lighting and pole lighting on an overall sense of perceived safety in pedestrian areas.

To measure women’s perceived safety in response to different lighting conditions, we designed a structured survey informed by an extensive review of the existing literature. Prior research has consistently identified several lighting characteristics that influence perceptions of safety, including visibility of the path, visibility of the surrounding area, the message conveyed by the lighting (e.g., maintenance or neglect), the ability to recognize facial features, and the presence or absence of glare. These five factors were the most frequently cited across peer-reviewed studies as key contributors to perceived safety. Accordingly, each factor was translated into a corresponding survey item to capture participants' perceptions after experiencing each virtual lighting scenario. Table 2 presents these factors alongside the scholars who have highlighted their importance in previous research.

Table 5: Summary of supporting literature related to key survey questions on perceived safety.

Survey Questions	Supporting Studies	Key Findings
Visibility of the path and surrounding	Taner et al. 1997| Dravitzki et al. 2003| Fisher and Nasar 1992| | Dastgheib 2018| Cellucci et al. 2016| Wänström 2013|	Improved visibility of the path and surrounding creates a sense of safety and encourages outdoor activities, resulting in an increased presence of people in an area.
Facial recognition	Dastgheib 2018| Boyce 2014| Lin et al. 2015| Calleri et al. 2019| Li et al. 2023| Knight 2010| Yang and Fotios 2015| Painter 1996|	Recognizing facial features is valuable in understanding the intention of an approaching person and makes people feel safer.
Glare	Peña-García et al. 2015| Knight 2010| | Dastgheib 2018| Boyce et al. 2000|	Uniform lighting without glare makes people feel safer.
Message	Fotios et al. 2018| Boyce 2014| Dastgheib 2018|	Lighting has an indirect effect on the perception of safety because a well-lit space sends the message that someone cares about this place, and it is worthy of being designed.

In terms of using VR technology as a research tool, there have been several studies that focused on direct comparisons between real and virtual environments, examining how cognitive and affective environmental appraisal and human movement patterns correspond in both settings (Westerdahl et al., 2006; Kort et al., 2003; Bishop & Rohrmann, 2003; Skorupka, 2009; Haq et al., 2005; Dalton, 2003; Witmer et al., 1996). Kuliga et al. (2015) concluded that VR has the potential to be a valuable research tool for studies in human–environment interactions. Bellazzi et al. (2022) compared lighting conditions in VR and real environments by reviewing thirty-three manuscripts that examined properties of light, including brightness, Correlated Color Temperature (CCT), distribution, contrast, evenness, and glare. Their results indicated that the lit virtual environment was perceived as similar to the real one, with no significant differences in the perception of lighting appearance and lighting levels in both daylit and electrically lit environments. Additionally, Chen et al. (2009) investigated the validity of using VR for lighting research and concluded that VR could accurately present lighting attributes, with human subjects expressing high levels of satisfaction with VR reproductions. In another study, Scorpio et al (2020) modeled a space in VR to evaluate the potential of using VR to represent lighting characteristics such as brightness, CCT, and distribution and concluded that lighting characteristics can be transferred using VR.

VR occupies a middle ground between real-world environments and static media such as photographs or videos. It offers a higher level of immersion and interactivity compared to traditional visual tools, thereby conveying spatial and lighting conditions more effectively. However, it still falls short of fully replicating real-world experiences. As previous research has demonstrated that VR can be a valuable tool in lighting studies, we employed VR as a research method to evaluate perceived safety under various lighting scenarios. We are aware that the most accurate way to assess safety perception would be to construct full-scale environments with actual lighting installations, allowing participants to walk through and directly experience the conditions. While such an approach would likely yield the most realistic responses, the substantial costs and logistical challenges make it largely impractical. VR offers a feasible and effective alternative that balances realism with flexibility and cost-efficiency.

2 RESEARCH DESIGN

To evaluate the effect of different lighting conditions on women's perceived safety and address our research questions, we devised four distinct lighting scenarios. Using Revit, we modeled a residential street typical of a medium-sized city in the United States. Subsequently, we integrated lighting layers in Twinmotion to create virtual reality simulations, which provided a controlled environment where participants could experience each lighting condition and evaluate their perceived safety. This approach ensured that our findings were derived from realistic and immersive representations of urban lighting. Figure 1 indicates the four lighting scenarios as they were:

Bollard lighting + Cold Color Temperature of the light source

Bollard lighting + Warm Color Temperature of the light source

Pole lighting + Cold Color Temperature of the light source

Pole lighting + Warm Color Temperature of the light source.

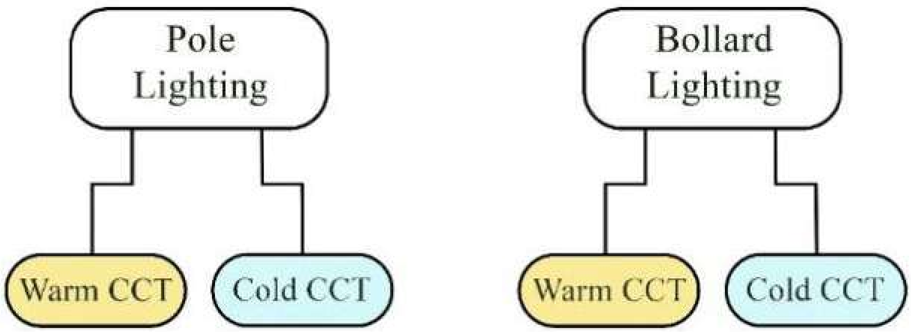

Figure 3: Four lighting scenarios using a 2x2 factorial approach. Diagram by the author.

These four lighting scenarios made an experimental two-by-two factorial design experiment. In addition to these lighting scenarios, we included a baseline level representing the typical lighting conditions found in current residential urban areas, which featured pole lighting installed on both sides of the street, illuminating the street and sidewalk. This setup reflects the common lighting configuration observed in many urban neighborhoods.

The study was conducted in Manhattan, Kansas, involving 50 female participants who interacted with these simulated virtual environments. Each participant wore a VR headset and navigated through a simulated street where the different lighting conditions were presented. After experiencing each scenario, participants completed a survey to self-report their perceived safety. This method allowed for the subjective evaluation of safety perceptions in a controlled and immersive setting. The survey comprised six questions designed to assess participants' perceived safety using a Likert scale (1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree). As mentioned earlier, five of these questions indirectly gauged perceived safety by employing criteria extracted from previous research. The survey questions focused on visibility of the path, visibility of the surrounding environment, facial recognition, glare and the message of lighting. Also, we added one question which directly inquired about participants' perceived safety by prompting them to self-assess their perceived safety. The inclusion of both direct and indirect questions aimed to evaluate the reliability of the survey questions and assess the alignment between responses to indirect queries and the direct inquiry regarding perceived safety. Figure 2 indicates the experiment process and Figures 3 and 4 show the lighting scenarios.

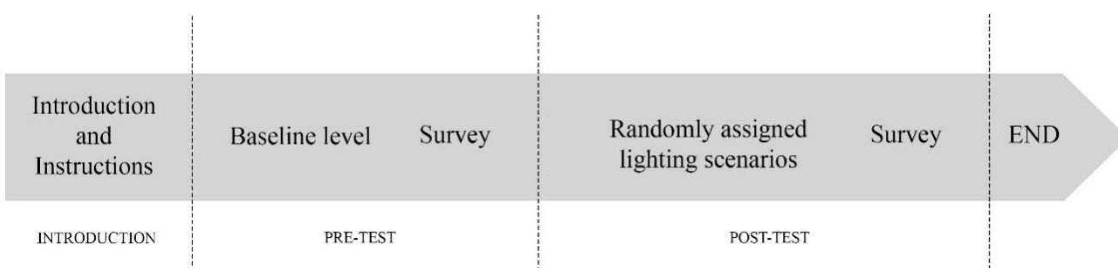

Figure 4: Experiment process. Diagram by the author.

Figure 5: Baseline condition. Photo (3D rendering) by the author.

Figure 6: Four proposed lighting scenarios. Photo (3D rendering) by the author.

3 RESULTS

The study recruited female volunteers from Manhattan, Kansas, ensuring a diverse pool of participants with varied backgrounds and experience walking at night. The participants were stratified into three distinct categories: 18-30, 31-50, and 61-65. The distribution included 27 individuals in the 18-30 age group, 17 in the 31-50 range, and 6 in the 61-65 category. Additionally, the sample encompassed a mix of international and American volunteers, with 21 participants coming from various international backgrounds and 29 from the United States. In terms of ethnicity, the majority of participants, comprising 45 individuals, identified as white, while 5 participants were African-American or other nationalities. Furthermore, participants were classified into five distinct walking habit categories.

First, a Cronbach's Alpha test was conducted to assess the internal consistency or reliability of the survey. Typically, a Cronbach's alpha value exceeding 0.70 is internally consistent (Peterson, 1994). The analysis was performed using R Studio version 2023.12.1+402 and resulted in a Cronbach's alpha coefficient of 0.83. Additionally, a Confirmatory Factor Analysis (CFA) was used to validate the measurement model for perceived safety across lighting scenarios. The survey responses to five questions (Q1–Q5), designed to measure the latent variable "perceived safety," were analyzed to assess whether the observed variables reliably represent the underlying construct. CFA was employed because it allows for the evaluation of the relationship between observed variables (survey questions) and their associated latent variable, ensuring the survey's validity. To conduct the analysis, R Studio was used, and the results indicated an acceptable model fit. The Chi-square value was 7.022 with a p-value of 0.219, the CFI value of 0.931 and the TLI value of 0.952, the RMSEA value was 0.030, and the SRMR value was 0.012.

Second, we aimed to compare women's perceptions of safety across different lighting scenarios and their experiences in the baseline condition and sought to identify any notable differences or improvements in perceived safety. To conduct the comparison, we employed repeated-measure ANOVA and post hoc tests. Repeated measure ANOVA is a statistical technique used for analyzing data with multiple measurements taken from the same subjects under different conditions or time points. The results of the ANOVA test revealed a significant increase in perceived safety in each lighting scenario compared to the baseline level. Additionally, the post hoc test results, shown in the following table (Table 3), indicate significant changes in perceived safety.

Table 6: Comparison between baseline and proposed lighting conditions

	Proposed Lighting Conditions	T-statistics	P-value	Adjusted P-value (Bonferroni Correction)
Baseline Lighting Condition	BOLLARD + CoolCCT	13.15	< 0.01***	< 0.01***
	BOLLARD + WarmCCT	15.78	< 0.01***	< 0.01***
	POLE + CoolCCT	7.53	< 0.01***	< 0.01***
	POLE + WarmCCT	9.36	< 0.01***	< 0.01***

***Significant at the 1% level

By creating a two-by-two factorial design experiment, we aimed to examine the main and interaction effects of color temperature and lighting height (Type) on perceived safety. The interaction effect assesses whether the influence of color temperature on perceived safety varies based on the lighting height—specifically, whether it differs between bollard-mounted and pole-mounted lighting configurations. To evaluate both main and interaction effects, we employed repeated measures ANOVA. The following table (Table 4) presents the results of the repeated measures ANOVA.

Table 7: Analysis of variance (ANOVA) results for the main and interaction effects of lighting color and height on perceived safety.

	F value	Num DF	Den DF	Pr > F	η^2
COLOR (main effect)	6.117	1.00	49.00	< 0.01***	0.020
HEIGHT (main effect)	27.852	1.00	49.00	< 0.01***	0.124
COLOR: HEIGHT (interaction effect)	0.084	1.00	49.00	0.772	0.0002

***Significant at the 1% level

The results of the repeated measures ANOVA indicate that the p-values for both color temperature and lighting height are less than the predetermined significance level of 0.01. This suggests a significant main effect of both color temperature and lighting height on perceived safety. However, the p-value associated with the interaction between the independent variables (color temperature and lighting height) was significantly higher than 0.01, indicating that the interaction effect does not exert a statistically significant influence on perceived safety. Following this, we conducted paired t-tests with Bonferroni Correction as a post-hoc analysis to examine differences in perceived safety scores across the various lighting conditions. The results are presented in Table 5.

Table 8: Pairwise comparisons of lighting conditions using paired t-test.

Comparison	T- statistics	P-value	Adjusted P-value (Bonferroni correction)
WCCT + BOLLARD vs. WCCT + POLE	4.637	< 0.01***	< 0.01***
WCCT + BOLLARD vs. CCCT + BOLLARD	2.305	0.0253	0.152
WCCT + POLE vs. CCCT + POLE	1.494	0.141	0.848
CCCT + BOLLARD vs. CCCT + POLE	3.893	< 0.01***	< 0.01***

***Significant at the 1% level

The table presents the results of paired t-tests comparing different combinations of lighting height (BOLLARD vs. POLE) and color temperature (WarmCCT vs. ColdCCT) on women's perceived safety, with both unadjusted and Bonferroni-adjusted p-values. The comparisons "WarmCCT + BOLLARD vs. WarmCCT + POLE" (t-statistic: 4.64, adjusted p-value < 0.01) and "ColdCCT + BOLLARD vs. ColdCCT + POLE" (t-statistic: 3.89, adjusted p-value< 0.01) were statistically significant, indicating significant differences in perceived safety scores between these combinations. This suggests that lighting height has a notable impact on perceived safety. However, while the ANOVA analysis revealed a potential main effect of color temperature on perceived safety, the paired t-tests did not show statistically significant differences between pairs, indicating that color temperature alone did not lead to significant variations in perceived safety scores.

4 DISCUSSION

In this experiment, we examined the influence of both color temperature and the height of lighting fixtures on women's perceived safety. The ANOVA test results suggested a potential influence of color temperature on perceived safety. However, further analysis through post hoc testing did not reveal any statistically significant differences among the pairs related to color temperature.

As mentioned earlier, some researchers such as Maciejewski (2018), Bullough and Skinner (2015), and others (Boyce, 2000; Peña-García et al., 2015; Knight, 2010) concluded that higher color temperature is directly correlated with higher perceived safety. Meanwhile other studies show the opposite. Saad et al. (2021) found that uniformity and warm color light are important factors in the perception of safety. Similarly, Liu et al. (2022) concluded that people feel safer if nighttime light is warm and uniform. In our research, the results indicated that color temperature does not significantly impact the women' perception of safety. Therefore, we concluded that although color temperature can influence the mood of a space, it does not dramatically change perceived safety. These results specifically reflect women's perceptions of safety in relation to lighting color and may differ when gender is not considered as a factor.

Another question we investigated was the potential interaction effect between lighting height (type) and the color temperature of the light source on women's perceived safety. Specifically, we aimed to determine if the impact of lighting height on perceived safety depends on the color temperature. To explore this, we conducted an ANOVA test to check for any statistically significant differences in perceived safety when considering the effects of both variables simultaneously. The results of the ANOVA test were not significant, with the p-value exceeding the acceptance threshold. This indicates that, within the parameters of our research, there is no significant interaction effect between lighting height and color temperature on perceived safety. In other words, the effect of lighting height on perceived safety does not depend on the color temperature of the lighting.

However, the height of the lighting fixtures did emerge as an important variable. Our statistical analysis revealed a significant effect of lighting fixture height on women's perceived safety. The robustness of this finding was underscored by the ANOVA results, which provided strong evidence of the influence of lighting fixture height on perceived safety. Furthermore, the subsequent post-hoc test yielded consistent and highly valid results, further confirming the significance of lighting fixture height in shaping perceptions of safety in urban environments.

Based on the results from the post-hoc analysis, participants reported feeling safer in scenarios where bollard lighting was added as a complement to pole lighting, and scenarios that included bollard lighting consistently resulted in higher perceived safety scores, regardless of the color temperature. These findings suggest that its use, in conjunction with traditional pole lighting, can improve the overall sense of safety in urban settings. It is also important to note that light levels were kept consistent across all scenarios, ensuring that the overall illumination remained the same whether pole lighting or a combination of both was used.

The results of this experiment align with findings from the literature review, which have emphasized the importance of bollard lighting in enhancing perceived safety. However, a key distinction is that most previous studies focused primarily on pedestrian safety from vehicles, whereas our research concentrated solely on the perceived crime safety. Another significant difference in our study is the use of bollard lighting as a complement to pole lighting, whereas previous research typically evaluated bollard lighting as an alternative to pole lighting. This complementary approach appears to notably enhance the sense of safety, suggesting that integrating both lighting types could be a more effective strategy for urban lighting design than relying on one type alone.

As previous research suggests, one factor influencing women' s preference for bollard lighting could be related to the intentional design it represents. Bollard lighting often conveys a sense that the lighting was thoughtfully planned and tailored to the environment, which can enhance the perception that the space is well-maintained and prioritized for safety. Furthermore, the presence of bollard lighting may create an impression that the path is important enough to warrant special attention and investment. This perception can contribute to a heightened sense of safety and comfort for pedestrians, reinforcing the idea that the area is considered valuable and deserving of meticulous design.

Another reason for the preference for bollard lighting is its human-scale design, which makes it more relatable and acceptable to women. Bollard lighting is typically positioned closer to the ground, creating a more intimate and approachable environment. This human-scale aspect of bollard lighting enhances the feeling of personal safety and comfort, as it is perceived as more considerate of pedestrian needs, making spaces feel more welcoming.

Overall, these results suggest that the intentionality of design—such as the thoughtful combination of bollard and pole lighting—has a greater impact on women's perceived safety than the specific characteristics of the light itself, such as color temperature. When women feel they are at the center of the design process and see that their safety is valued enough to justify a dedicated pedestrian lighting layout, separate from vehicular lighting, it builds greater trust in the urban environment. This sense of care and prioritization is more influential than technical lighting attributes alone.

5 CONCLUSION

In conclusion, this study investigated the impact of different lighting conditions on women's perceived safety in urban environments, focusing specifically on the integration of bollard and pole lighting with varying color temperatures. The research centered on women's experiences, recognizing that women often face heightened concerns about safety in public spaces after dark. By prioritizing their perspectives, the study aimed to inform more inclusive and responsive urban lighting strategies that support equity and well-being in the built environment. Through immersive virtual reality simulations, participants evaluated five distinct lighting scenarios, including combinations of bollard and pole lighting with cold and warm color temperatures, alongside a baseline scenario representing typical residential street lighting.

Moreover, while previous research has often emphasized the role of color temperature in perceived safety, our study revealed that, within the parameters examined, color temperature did not significantly influence women 's perceived safety scores. Instead, the height of lighting fixtures emerged as a critical factor. Women felt safer walking on a street with both bollard lighting and pole lighting. This can be attributed to two main factors. First, bollard lighting provides human-scale illumination, enhancing the sense of security. Second, the presence of bollard lighting conveys that the space is thoughtfully designed and maintained, which in turn contributes to a heightened perception of safety. This is particularly important for women, who often experience a heightened awareness of safety risks in public spaces, especially after dark. Women frequently adjust their behaviors such as avoiding certain routes or limiting time outside at night due to perceived threats. These findings suggest that urban lighting strategies should prioritize thoughtful design to create environments that are both safe and inviting for pedestrians. Lastly, we found no significant interaction effect between lighting height and color temperature on perceived safety. In other words, the effect of lighting height on perceived safety does not depend on the color temperature of the light source.

As our findings suggest that the presence of bollard lighting significantly enhances perceived safety, we recommend that urban design policymakers incorporate these findings into their regulations and guidelines. By legislating for the inclusion of bollard lighting in urban design, policymakers can help create safer, more welcoming environments. Furthermore, professional organizations such as the Illuminating Engineering Society (IES) could build on these insights to expand the existing standards, particularly by placing greater emphasis on lower-height lighting solutions. This approach aligns with the goal of improving public safety and supports broader urban planning objectives aimed at enhancing the livability and walkability of city spaces. Also, these findings emphasis the importance of human-scale design in shaping psychological and behavioral responses to outdoor spaces. While traditional lighting design has often prioritized illumination levels for visibility and general coverage, this research redirects attention toward how pedestrian-oriented lighting strategies can influence women's emotional experiences and perceptions of safety.

As a design takeaway for landscape architects, lighting designers, and urban designers, we recommend first mapping the placement of pole lighting to deliver broad, uniform illumination. Once that framework is established, add a secondary layer of bollard fixtures at a lower intensity to trace the pedestrian path and create a more intimate, human-scale environment that enhances perceived safety. This layered approach allows for greater spacing between pole lights than is typically seen in current urban lighting practices. Additionally, integrating presence sensors on pole fixtures can be beneficial. In this approach, bollards provide a steady, low-level glow to maintain baseline visibility, while pole lights increase to higher levels only when pedestrian movement is detected. This responsive system improves energy efficiency and aligns illumination with actual human activity and safety needs. By treating lighting as an active design tool rather than a purely technical requirement, practitioners can craft public-realm spaces that feel legible, well-maintained, and socially welcoming—demonstrating how thoughtful lighting composition directly shapes spatial and social dynamics.

In this research investigation, the sample pool was limited due to financial constraints, allowing us to recruit 50 participants. Despite this limitation, it was possible to successfully engage volunteers and obtain valuable results. For future research, expanding the sample size is recommended, as larger samples tend to yield more reliable and generalizable results. Also, the experiment was conducted in Manhattan, Kansas, which is considered a relatively small and safe city. Therefore, participants in this study, may have a different definition and experience of safety. Future studies should consider using participants who live in cities with characteristics similar to the modeled environment to obtain more accurate results. Lastly, we acknowledge that our findings are based solely on women's experiences, and therefore, may not be fully generalizable to the broader population.

This experiment was based on an analysis of quantitative data, where participants self-evaluated their perceived safety through surveys, which we then analyzed using quantitative methods. While this approach provides valuable insights, for future research it would be beneficial to complement it with qualitative methods. Integrating qualitative methods, such as focus groups, could offer deeper insights by engaging a larger pool of survey participants and selecting a smaller subset for detailed discussions. Focus groups allow for open-ended discussions, providing richer and more nuanced information about the lighting conditions that significantly affect perceived safety. Qualitative data can add context to quantitative results, highlighting areas that require further investigation and offering explanations for observed patterns. Combining these methods would enhance the reliability and applicability of the findings, ultimately leading to better-informed decisions in lighting design and perceived safety.

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest with respect to the authorship or publication of this paper.

Ethnical Approval

This research was approved by the Institutional Review Board (IRB) at Kansas State University. Each participant provided informed consent through a verbal consent process prior to their involvement in the study.

REFERENCES

Baobeid, A., Koç, M., & Al-Ghamdi, S. G. (2021). Walkability and its relationships with health, sustainability, and livability: Elements of physical environment and evaluation frameworks. *Frontiers in Built Environment*, *7*, 721218. https://doi.org/10.3389/fbuil.2021.721218

Bellazzi, A., Bellia, L., Chinazzo, G., Corbisiero, F., D'Agostino, P., Devitofrancesco, A., ... & Salamone, F. (2022). Virtual reality for assessing visual quality and lighting perception: A systematic review. *Building and Environment*, *209*, 108674. https://doi.org/10.1016/j.buildenv.2021.108674

Bishop, I. D., & Rohrmann, B. (2003). Subjective responses to simulated and real environments: A comparison. *Landscape and Urban Planning*, *65*(4), 261-277. https://doi.org/10.1016/S0169-2046(03)00070-7

Blöbaum, A., & Hunecke, M. (2005). Perceived danger in urban public space: The impacts of physical features and personal factors. *Environment and Behavior*, *37*(4), 465-486. https://doi.org/10.1177/0013916504269643

Boomsma, C., & Steg, L. (2014). Feeling safe in the dark: Examining the effect of entrapment, lighting levels, and gender on feelings of safety and lighting policy acceptability. *Environment and Behavior, 46*(2), 193-212. https://doi.org/10.1177/0013916512453838

Boyce, P. R. (2014). *Human factors in lighting.* CRC Press.

Boyce, P. R., Eklund, N. H., Hamilton, B. J., & Bruno, L. D. (2000). Perceptions of safety at night in different lighting conditions. *International Journal of Lighting Research and Technology, 32*(2):79-91. https://doi.org/10.1177/096032710003200205

Bromley, R., Thomas, C., & Millie, A. (2000). Exploring safety concerns in the night-time city: Revitalising the evening economy. *Town Planning Review, 71*(1), 71. https://doi.org/10.3828/tpr.71.1.rnk3336381678247

Bullough, J. D., & Skinner, N. P. (2015). *Demonstrating urban outdoor lighting for pedestrian safety and security.* Rensselaer Polytechnic Institute. New York: University Transportation Research Center.

Calleri, C., Astolfi, A., Pellegrino, A., Aletta, F., Shtrepi, L., Bo, E., ... & Orecchia, P. (2019). The effect of soundscapes and lightscapes on the perception of safety and social presence analyzed in a laboratory experiment. *Sustainability, 11*(11), 3000. 1-19. https://doi.org/10.3390/su11113000

Cellucci, L., Bisegna, F., Gugliermetti, F., & Navvab, M. (2016). Lighting distribution affects pedestrians' sense of security. In *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)* (pp. 1-5). IEEE. https://doi.org/10.1109/EEEIC.2016.7555655

Chen, I. R., & Schnabel, M. A. (2009). Retrieving lost space with tangible augmented reality. In *International Conference on the Association for Computer-Aided Architectural Design Research in Asia 2009* (pp. 135-142). Retrieved April 22 from https://www.academia.edu/download/3465748/Lost_Space_CAADRIA09.pdf

Dalton, R. C. (2003). The secret is to follow your nose: Route path selection and angularity. *Environment and Behavior*, *35*(1), 107-131. https://doi.org/10.1177/0013916502238867

Dastgheib, S. (2018). *Light and perception of safety in-between buildings: The role of lighting in perception of safety from a female perspective in in-between spaces of residential areas* [Master's thesis, KTH Royal Institute of Technology].

Dravitzki, V., Cleland, B. S., Walton, D., & Laing, J. N. (2003). Measuring commuting pedestrians' concerns for personal safety and the influence of lighting on these concerns. In *Proceedings of the 26th Australasian Transport Research Forum* (pp. 1-14).

https://australasiantransportresearchforum.org.au/wp-content/uploads/2022/03/2003_Dravitzki_Cleland_Walton_Laing.pdf
Dubey, S., Bailey, A., & Lee, J. B. (2025). Women's perceived safety in public places and public transport: A narrative review of contributing factors and measurement methods. *Cities*, *156*, 105534. https://doi.org/10.1016/j.cities.2024.105534
Fisher, B. S., & Nasar, J. L. (1992). Fear of crime in relation to three exterior site features: Prospect, refuge, and escape. *Environment and Behavior*, *24*(1), 35-65. https://doi.org/10.1177/0013916592241002
Fisher, B. S., & Sloan, J. J., III. (2003). Unraveling the fear of victimization among college women: Is the "shadow of sexual assault hypothesis" supported?. *Justice Quarterly, 20*(3), 633-659. https://doi.org/10.1080/07418820300095641
Fotios, S., Monteiro, A. L., & Uttley, J. (2019). Evaluation of pedestrian reassurance gained by higher illuminances in residential streets using the day–dark approach. *Lighting Research & Technology*, *51*(4), 557-575. https://doi.org/10.1177/1477153518775464
Haans, A., & De Kort, Y. A. (2012). Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology*, *32*(4), 342-352. https://doi.org/10.1016/j.jenvp.2012.05.006
Haq, S., Hill, G., & Pramanik, A. (2005, June). Comparison of configurational, wayfinding and cognitive correlates in real and virtual settings. In *Proceedings of the 5th International Space Syntax Symposium* (Vol. 2, pp. 387-405). https://www.researchgate.net/profile/Adetania-Pramanik-2/publication/228749346_Comparison_of_configurational_wayfinding_and_cognitive_correlates_in_real_and_virtual_settings/links/542e15d90cf27e39fa95fe4a/Comparison-of-configurational-wayfinding-and-cognitive-correlates-in-real-and-virtual-settings.pdf
Keane, C. (1998). Evaluating the influence of fear of crime as an environmental mobility restrictor on women's routine activities. *Environment and Behavior*, *30*(1), 60-74. https://doi.org/10.1177/0013916598301003
Knight, C. (2010). Field surveys of the effect of lamp spectrum on the perception of safety and comfort at night. *Lighting Research & Technology*, *42*(3), 313-329. https://doi.org/10.1177/1477153510376794
Kort, Y. A. D., Ijsselsteijn, W. A., Kooijman, J., & Schuurmans, Y. (2003). Virtual laboratories: Comparability of real and virtual environments for environmental psychology. *Presence: Teleoperators & Virtual Environments, 12*(4)*, 360-373.*
Kuliga, S. F., Thrash, T., Dalton, R. C., & Hölscher, C. (2015). Virtual reality as an empirical research tool—Exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems*, *54*, 363-375.
Li, Z., Li, X., & Jiang, B. (2023). How people perceive the safety of self-driving buses: A quantitative analysis model of perceived safety. *Transportation Research Record, 2677*(1)*, 1356-1366. https://doi.org/10.1177/03611981221104455*
Lin, Y., & Fotios, S. (2015). Investigating methods for measuring face recognition under lamps of different spectral power distribution. *Lighting Research & Technology*, *47*(2), 221-235. https://doi.org/10.1177/1477153513505306
Liu, M., Zhang, B., Luo, T., Liu, Y., Portnov, B. A., Trop, T., ... & Liu, Q. (2022). Evaluating street lighting quality in residential areas by combining remote sensing tools and a survey on pedestrians' perceptions of safety and visual comfort. *Remote Sensing*, *14*(4), 826. https://doi.org/10.3390/rs14040826
Loewen LJ, Steel GD, Suedfeld P. (1993). Perceived safety from crime in the urban environment. *Journal of Environmental Psychology*, *13*(4), 323-331. https://doi.org/10.1016/S0272-4944(05)80254-3
Maciejewski, W. F. (2018). *Using virtual reality in quantifying the relation between color temperature of public lighting and perceived personal safety* [Master's thesis, Jan Matejko Academy of Fine Arts]. https://www.researchgate.net/profile/Wojciech-Maciejewski-2/publication/319684955_Using_virtual_reality_in_quantifying_the_relation_between_colour_temperature_of_public_lighting_and_perceived_personal_safety/links/5bb45aba92851ca9ed36f5b8/Using-virtual-reality-in-quantifying-the-relation-between-colour-temperature-of-public-lighting-and-perceived-personal-safety.pdf

Messa, F., Scarponi, L., Abdelfattah, L., Carpentieri, G., Martinelli, V., Stiuso, T., & Gorrini, A. (2025). Modeling women's perceived level of safety at night in Milan. *Journal of Transport Geography*, *127*, 104243. https://doi.org/10.1016/j.jtrangeo.2025.104243

Mitra, P., & Bardhan, S. (2017). Tracing the importance of Safety Audit in making Inclusive Cities: A step towards Smart Cities. *Procedia Environmental Sciences*, *37*, 420-428. https://doi.org/10.1016/j.proenv.2017.03.011

Mushtaha, E., Hussien, A. A., Arar, M., Salleh, S. A., Mohammad, A., Masoud, W., ... & Almubyedh, H. (2022). Artificial lighting systems and the perception of safety in underpass tunnels. *Tunnelling and Underground Space Technology*, *122*, 104376. https://doi.org/10.1016/j.tust.2022.104376

Painter, K. (1996). The influence of street lighting improvements on crime, fear and pedestrian street use, after dark. *Landscape and Urban Planning, 35*(2–3), 193–201. https://doi.org/10.1016/0169-2046(96)00311-8

Paskovic A. (2012). *Urban lighting: Planning for public spaces in Vancouver's Southeast False Creek* [Doctoral dissertation, Queen's University].

Park, A. J., Calvert, T. W., Brantingham, P. L., & Brantingham, P. J. (2008). The Use of virtual and mixed r eality environments for urban behavioural studies. *PsychNology Journal*, *6*(2). https://www.researchgate.net/profile/Paul-Brantingham/publication/220168818_The_Use_of_Virtual_and_Mixed_Reality_Environments_for_Urban_Behavioural_Studies/links/02bfe50cf436428d10000000/The-Use-of-Virtual-and-Mixed-Reality-Environments-for-Urban-Behavioural-Studies.pdf?_sg%5B0%5D=started_experiment_milestone&origin=journalDetail

Peterson, R. A. (1994). A meta-analysis of Cronbach's coefficient alpha. *Journal of Consumer Research*, *21*, 381-391. https://www.jstor.org/stable/2489828

Peña-García, A., Hurtado, A., & Aguilar-Luzón, M. C. (2015). Impact of public lighting on pedestrians' perception of safety and well-being. *Safety Science, 78,* 142-148. https://doi.org/10.1016/j.ssci.2015.04.009

Saad, R, Portnov, B. A., & Trop, T. (2021). Saving energy while maintaining the feeling of safety associated with urban street lighting. *Clean Technologies and Environmental Policy*, *23*(1), 251-269. https://doi.org/10.1007/s10098-020-01974-0

Scorpio, M, Laffi, R, Masullo, M, Ciampi, G, Rosato, A, Maffei, L, & Sibilio, S. (2020). Virtual reality for smart urban lighting design: Review, applications and opportunities. *Energies*, *13*(15):3809. https://doi.org/10.3390/en13153809

Skorupka, A. (2009, June). Comparing human wayfinding behavior in real and virtual environment. In *Proceedings of the 7th International Space Syntax Symposium* (Vol. 104, pp. 1-7). Stockholm: KTH Royal Institute of Technology. http://sss7.org/Proceedings/10%20Architectural%20Research%20and%20Architectural%20Design/104_Skorupka.pdf

Oc, T., & Tiesdell, S. (Eds.). (1997). *Safer city centres: Reviving the public realm*. Sage.

Valentine, G. (1989). The geography of women's fear. *Area*, *21*(4), 385–390. http://www.jstor.org/stable/20000063

Vogel, Mary, & Pettinari, J. (2002). *Personal safety and transit: Paths, environments, stops, and stations.* [Master's thesis, University of Minnesota]. https://hdl.handle.net/11299/854

Westerdahl, B., Suneson, K., Wernemyr, C., Roupé, M., Johansson, M., & Allwood, C. M. (2006). Users' evaluation of a virtual reality architectural model compared with the experience of the completed building. *Automation in Construction, 15*(2):150-165. https://doi.org/10.1016/j.autcon.2005.02.010

Witmer, B. G., Bailey, J. H., Knerr, B. W., & Parsons, K. C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, *45*(4), 413-428. https://doi.org/10.1006/ijhc.1996.0060

Wänström Lindh, U. (2013). Distribution of light and atmosphere in an urban environment. *Journal of Design Research*, *11*(2), 126-147. https://doi.org/10.1504/JDR.2013.055138

Yang, B., & Fotios, S. (2015). Lighting and recognition of emotion conveyed by facial expressions. *Lighting Research & Technology*, *47*(8), 964-975. https://doi.org/10.1177/1477153514547753

Yu, C. Y. (2015). Built environmental designs in promoting pedestrian safety. *Sustainability*, *7*(7):9444-9460. https://doi.org/10.3390/su7079444