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Effect of Street Light Intervals on Distance to Unknown Approaching Pedestrian That Causes Discomfort

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ABSTRACT

Street lighting is one of the effective methods for improving the impression of streets at night. Among the some factors that control the effect of street lighting, the intervals between light and light have a significant impact on the impression of streets. In this study, an experiment using virtual environment technology is conducted to verify the effect of street light intervals on the feeling of safety and discomfort of pedestrians at night. Through the quantitative analysis of the experimental results, the objective of this study is to obtain knowledge on the planning and design of street lighting that reduce discomfort and provides sense of safety. Ten college students participated in the experiment. We arranged street lights and a moving human avatar in the virtual environment. The participants had been asked to press the button of the hand controllers when they felt discomfort that they did not want the avatar to approach any closer. The results showed that the distance at which pedestrians begin to feel uncomfortable with oncoming pedestrians is significantly greater when the street light interval is 100 m compared to when the street light interval is 12.5 m. The wider the street light intervals, the greater the distance at which the participants feel discomfort that they did not want the avatar to approach any closer.

Keywords: Architectural design, Immersive virtual environment, Subjective experiment

INTRODUCTION

Walking through dark streets at night can evoke discomfort. Previous research, for example, Kinashi et al.'s (2010) study, has suggested that factors such as "distance," "pedestrian traffic," "brightness," and "visibility" significantly influence pedestrian route choices during nighttime. Among these factors, "brightness" has emerged as particularly influential, as indicated by analysis of pedestrian route choice models.

Street lighting plays a crucial role in illuminating nighttime environments. Adequately lit streets enhance pedestrian visibility and promote safety. However, despite the presence of well-lit thoroughfares in urban areas, several backstreets remain dimly lit and lack sufficient illumination from street lights. This raises the following question: What is the optimal spacing between street lights to ensure pedestrian visibility and mitigate discomfort in poorly lit areas?

This study investigated the effect of street-light spacing on pedestrian discomfort levels when approaching individuals. Utilizing virtual environment technology, the experiment assessed the influence of different street-light intervals on the distance at which pedestrians begin to feel uncomfortable. Through a quantitative analysis of the experimental outcomes, this study aims to provide insights for designing street-lighting systems that facilitate safe nighttime pedestrian navigation.

EXPERIMENT

Method

Ten students were recruited as participants for the experiment that was conducted at the Virtual Environment Laboratory of Chiba University. The participants were engaged in a task in a virtual environment. Measurements were conducted across various street-light intervals to explore alterations in the discomfort-inducing distance. The participants used a head-mounted display (Vive Pro Eye/Vive) positioned upright within an infinitely generated virtual street environment.

Virtual streets were designed to replicate dimly illuminated back alleys devoid of light sources apart from street lights. Different street-light intervals were implemented across the experimental conditions with a virtual human avatar representing an approaching pedestrian placed at the end of the street. The movement of the avatar toward the participant was controlled by the experimenter. The participants were instructed to press a designated button on the controller upon experiencing discomfort from the approaching avatar. Distance changes between the participant and approaching pedestrian were assessed across varying street-light intervals.

Conditions

A schematic of the virtual street layout is demonstrated in Figure 1. Street-light intervals were set to 12.5 m, 25 m, 50 m, and 100 m, as illustrated in Figures 2 and 3. Four distinct conditions were established by evenly distributing street lights at each interval. Participants observed these streets in a standing position. The height of the street-light pillars and light sources was fixed at 5 m. The light source parameters for the street lights were standardized using the Vizard6 program with the following settings: intensity, 5; linear attenuation, 0.5; constant attenuation, 1; quadratic attenuation, 0.5; and light color: 1,1,1 (white).

A consistent female avatar was used as the approaching pedestrian under all conditions. The avatar's initial position was set at 20 m from the participant's front, approaching a travel speed of 0.8 m/s. This movement speed was intentionally set slower than the average adult walking speed (1.0–1.5 m/s) to facilitate the exploration of the distance at which participants began to feel discomfort when approaching pedestrians.

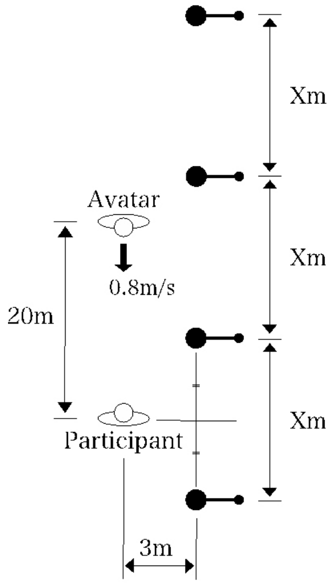

Figure 1: Virtual space layout.

Figure 2: Virtual space in each condition (left: 12.5 m, right: 25 m).

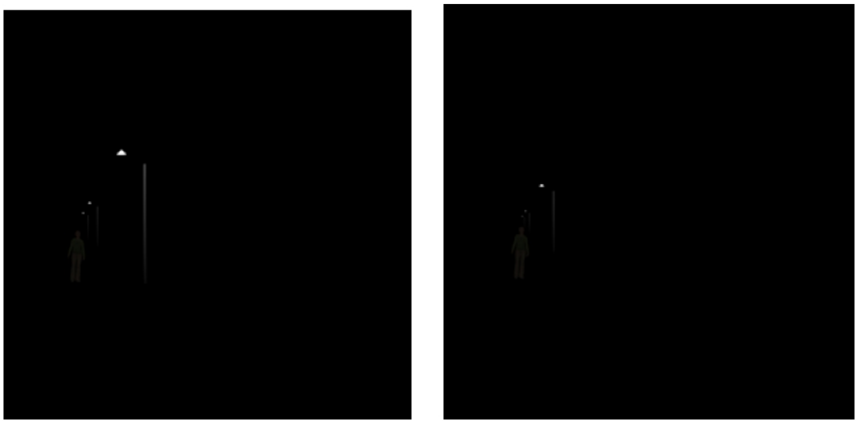

Figure 3: Virtual space in each condition (left: 50 m, right: 100 m).

Measurement

Participants received an overview of the experiment prior to commencement. Subsequently, the participants were instructed to use a head-mounted display and hold the controller in one hand. To ensure familiarity with the experimental procedure, participants engaged in a single practice run.

Upon initiation, the participants were presented with a virtual street environment, after which the avatar began walking toward them. If the participants experienced discomfort owing to the approaching avatar, they were instructed to press the trigger button on the controller, prompting the avatar to halt. Furthermore, the distance between the avatar and participant was recorded for each condition.

In this study, the stopping-distance method was employed as the primary measurement technique. Originating from Hayduk's (1978) research, the stopping distance method is recognized as a reliable approach for gauging personal spaces. By using this method, we assessed how the participants' discomfort levels varied across different street-light intervals by measuring their personal space.

Two measurements were conducted for each condition; moreover, the average of the two recordings was calculated to determine the ratings for each condition. The conditions were randomized for each participant to mitigate the potential bias stemming from the sequential presentation of the experimental conditions.

RESULTS

The average outcomes are depicted in Figure 4, revealing notable variations in the stopping positions of the participants relative to the street-light interval. To statistically validate these observations, a multiple comparison test was conducted using the Bonferroni method (5% significance level), treating "street-light interval" as a factor. The results of this analysis revealed a significant disparity between the 12.5-m and 100-m conditions ($p = 0.029$). Additionally, significant trends were observed between the 12.5-m and 50-m conditions, and between the 25-m and 100-m conditions ($p = 0.092$ and $p = 0.080$, respectively).

On individual examination, the participants exhibited significant variations in their standard stopping positions. Although some participants halted their avatars approximately 4 m from the approaching pedestrian, others maintained distances exceeding 10 m. To standardize the data, each participant's values recorded for the 25-m, 50-m, and 100-m conditions were normalized by dividing them by the corresponding values obtained for the 12.5-m condition (see Figure 5).

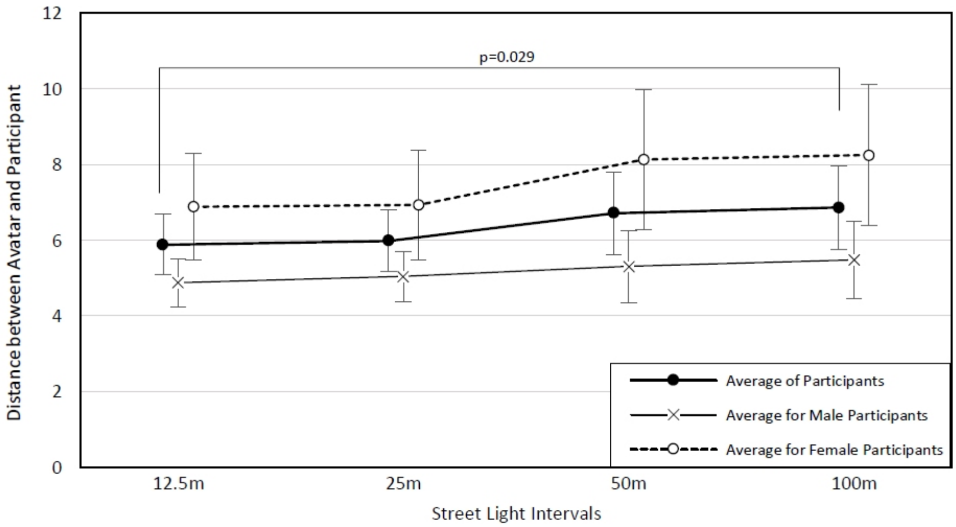

Figure 4: Street-light intervals and avatar stop.

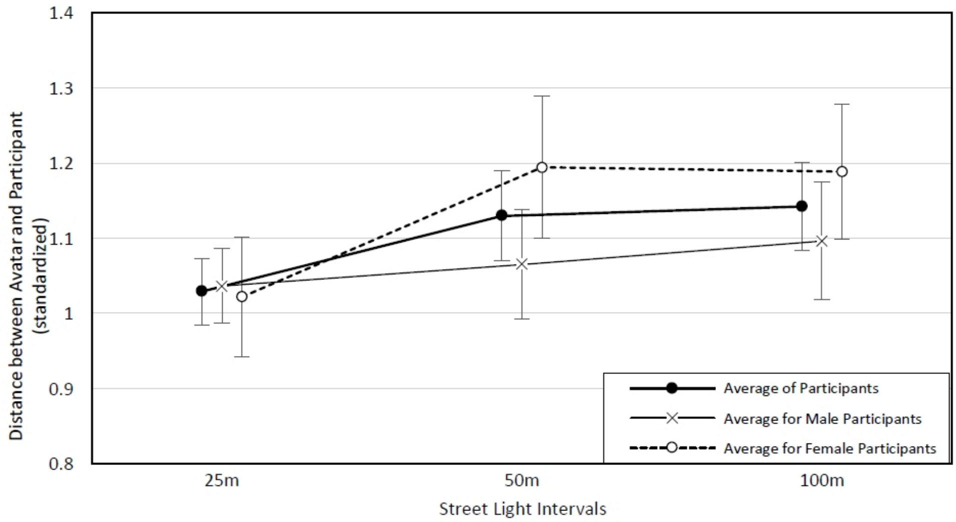

Figure 5: Street-light intervals and avatar stop (standardized).

DISCUSSION

Consideration of Street-Light Intervals

The distance at which the participants stopped their avatars was significantly greater in the condition with a street-light interval of 100 m than that with a street-light interval of 12.5 m. This may be owing to the fact that the ambient brightness and the way the avatar was illuminated varied with the street-light interval. Similarly, the distance at which participants stopped their avatars, which established a significant trend for the 12.5-m and 50-m, and 25-m and 100-m combinations, could also be owing to changes in the brightness of the environment.

These findings suggest that as nighttime streets become less illuminated, pedestrians experience increased discomfort from approaching individuals. Manipulating street-light intervals could, therefore, be an effective strategy for designing streets where pedestrians feel more at ease. This conclusion underscores the significance of street lighting in mitigating pedestrian discomfort and highlights the potential of urban planning interventions to enhance pedestrian experience in nighttime environments.

Consideration of the Distance at Which the Participant Stopped the Avatar

In our study, although statistical significance was not observed, the participants' sex may have influenced the distance at which the avatar was stopped. Male participants tended to stop their avatars at distances ranging from 4 to 6 m on average, whereas female participants stopped their avatars at distances averaging 6–9 m. Notably, even under identical street-light intervals, female participants maintained greater distances from the approaching avatar.

These findings are consistent with those of Paul et al. (1988), suggesting gender-related differences in personal spaces. Although our study did not delve deeply into the underlying mechanisms, it highlights the potential impact of sex on perceived comfort levels in nighttime environments.

Furthermore, sex may have influenced the changes in stopping distances observed. The standardized data transitions in Figure 5 show that as street-light intervals increased, so did the distance at which the avatars were stopped for both sexes. However, while the male average ranged from 1 to 1.1 in standardized values, the female average ranged from 1 to 1.3, suggesting a greater change in females. Post-experiment interviews revealed that many female participants stopped using their avatars because of fear, whereas male participants reported discomfort. This difference in judgment may have influenced the results.

Consideration of the Causes of Increased Uncomfortable Feelings

The ongoing discussion underscores a clear trend: the participants' discomfort with the approaching avatar increased as the street-light interval widened. We attribute this trend to variations in how the avatar is illuminated, which are influenced by changes in the street-light interval. Post-experiment interviews revealed that several participants experienced a temporary loss of sight of the avatar when the street-light interval was set to 50 m or 100 m, eliciting a sense of fear upon rediscovery.

This anecdotal evidence suggests that longer street-light intervals result in shorter durations of illumination for the avatar, thereby impeding the participants' ability to accurately perceive their movements. Consequently, the difficulty in tracking the avatar's movements likely contributed to the heightened discomfort experienced by the participants.

CONCLUSION

This study explored the impact of varying street-light intervals on pedestrian discomfort levels when approaching an individual. The findings of this study are summarized as follows:

- Participants exhibited a significantly greater discomfort-inducing distance with street-light intervals of 100 m compared with 12.5 m.
- A clear trend emerged, indicating that as street-light intervals increased, so did the distance at which pedestrians began to feel uncomfortable with approaching individuals.

These findings underscore the crucial role of street-lighting design in shaping pedestrian perceptions of safety and comfort in nighttime environments. Further research on the nuanced effects of street lighting on pedestrian experience is warranted to develop evidence-based strategies for urban planning and design.

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