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Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape

Antal Haans*, Yvonne A.W. de Kort

Eindhoven University of Technology, The Netherlands

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ABSTRACT

The relationship between light and perceived safety at night is intuitively strong, yet theoretically and empirically its workings are largely unknown. Intelligent dynamic road lighting, which continuously adapts to the presence and behavior of users, can light the street only when and where it is needed. As such, it offers a solution to the energy waste and luminous pollution associated with conventional road lighting. With this innovation, however, new questions emerge about the effect of lighting on perceived safety. We need to consider not only how much lighting pedestrians need to feel safe, but also which parts of the street should be lit. In two experiments, we investigated the effect of different light distributions on perceived safety, and explored mediation by people's appraisal of three safety-related cues suggested in the literature: prospect (having an overview), escape (perceived escape possibilities), and refuge/concealment (perceived hiding places for offenders). Both experiments, one with stationary and one with walking participants, demonstrated that people prefer having light in their own immediate surroundings rather than on the road that lies ahead. This could be explained, partially, by changes in prospect, escape, and concealment. Against expectations, prospect was higher with lighting distributions in which participants' immediate surroundings, but not the more distant parts of the road, were most strongly lit.

1. Introduction

Street lighting is ubiquitous in modern day urban life. It is important for crime prevention, for orientation and obstacle avoidance at night, and for providing a general sense of safety to road users. As such, it supports nighttime commercial and leisure activities, and is essential for the freedom to go out at night, in particular to those vulnerable to or fearful of personal attacks (e.g., Keane, 1998). Lighting is important also for creating esthetically pleasing urban environments, which in turn affect the prestige of many modern cities (cf., Bouman, 1987). Despite these important functions, an increasing number of people are concerned with the possible drawbacks of excessive street lighting. This so-called photo or luminous pollution affects not only the amateur astronomer who is constrained by the city's sky glow, but has a detrimental effect on the health and well being of all humans (for an overview, see Navara & Nelson, 2007) and animals (e.g., on bird migration; Longcore & Rich, 2004).

At the same time, there is an increasing awareness of climate change and the impending shortage of energy sources. In the Netherlands, about 823,000 MWh per year are used by municipalities for public lighting, accounting, on average, for 60% percent of the local government's energy consumption (Agentschap NL, 2010; Taskforce Verlichting, 2011). This includes the lighting of streets at times when no street users are present, leading to energy waste and unnecessary luminous pollution. Taken together, these examples underline the clear and urgent need to reconsider the way in which we illuminate our streets at night (also Boyce, Fotios, & Richards, 2009).

1.1. Toward intelligent dynamic street lighting

Lighting technologies based on light emitting diodes (LEDs) are a promising innovation for street lighting. Their energy efficiency is rising steadily, and they offer better control over the illumination output. As such, LED technology offers new possibilities for dimming at periods with lower traffic densities, or adjustment of the light output to weather conditions. Combined with appropriate sensing technology to recognize the number, type, and location of road users, LED technology also offers the possibility of intelligent light-on-demand scenarios. Such intelligent dynamic lighting,

* Corresponding author. Human-Technology Interaction group, Department of Industrial Engineering & Innovation Sciences, Eindhoven University of Technology (IPO 1.35), P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands.
E-mail address: A.Haans@tue.nl (A. Haans).

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which adapts itself to the street user, can offer light only when and where it is needed most. As such it has the potential of reducing energy waste and luminous pollution without affecting functionality.

However, important choices have to be made with respect to how dynamic road lighting is implemented. When and where, for example, do pedestrians benefit most from street lighting? Do pedestrians prefer to have light in their immediate surroundings (i.e., there where they are walking), or would they prefer more light in the distance (i.e., on those parts of the street that lie ahead of them). Issues like these are irrelevant for conventional lighting where light is functioning all the time and everywhere, distributed equally across the lampposts. However, they pose a major challenge for dynamic road lighting scenarios. The distribution of light across the lampposts is but one out of a wide range of variables of which the effect on perceived safety is still unknown. As such, the possibility of dynamic road lighting requires, more than ever, a thorough understanding of the effect of lighting on street users, in particular with respect to their perceived personal safety.

1.2. Street lighting and perceived personal safety

We define perceived personal safety as a person's immediate sense of security, and an absence of anxiety of becoming victimized, when traveling through a particular environment (cf., Blöbaum & Hunecke, 2005). Street lighting is generally seen as the most important physical feature of an environment to affect perceived personal safety (e.g., Loewen, Steel, & Suedfeld, 1993; Nasar, Fisher, & Grannis, 1993; Nasar & Jones, 1997). The amount and uniformity of illuminance, and perhaps also light spectrum are found to affect perceived personal safety (e.g., Boyce, Eklund, Hamilton, & Bruno, 2000; Knight, 2009). Improving street lighting is also an effective means in combating crime. Although this has been subject to considerable debate (see Pease, 1999), the general consensus nowadays is that adequate street lighting can reduce crime rates in a street (for a recent meta-analysis, see Welsh & Farrington, 2008).

1.3. Three safety cues: prospect, escape, and concealment

Researchers have focused in particular on how people's sense of safety is influenced by features of the physical environment. Fisher and Nasar (1992) describe three such proximate cues: prospect, refuge, and escape. These cues are based on Appleton's (1975) prospect-refuge theory in which he argues that evolution has installed a preference for environments that offer shelter (refuge) and a good outlook over what is happening in the environment (prospect). People's appraisal of prospect will be high in the absence of physical features that hinder their field of view, such as trees, buildings, or a bend in the road. Street lighting too is expected to affect people's appraisal of prospect, and thus safety feelings. Adequate street lighting, for example, offers visibility, which is a prerequisite for prospect (Loewen et al., 1993).

The term refuge is used somewhat ambiguously by Fisher and Nasar (1992; also Loewen et al., 1993). For Appleton (1975), an environment high in refuge offers plenty possibilities for shelter (i.e., safe havens). For Fisher and Nasar, however, refuge is defined as the ease with which potential offenders can conceal themselves in a certain street. To avoid this ambiguity we use the term concealment rather than refuge (cf., Blöbaum & Hunecke, 2005; Nasar et al., 1993). Physical street characteristics that might increase people's appraisal of concealment include walls, bushes, trees, and other objects that create blind spots in which offenders might hide. Street lighting can reduce these blind spots, but might also cast shadows in which potential offenders can hide (Nasar & Jones, 1997).

The third and last proximate cue described by Fisher and Nasar (1992) is escape, which refers to the extent to which the environment offers possibilities for evading a possible assault. People's perception of escape might be influenced by such physical features as alleys and subway stations which might offer routes away from the assaulter. In addition, accessibility to other people is important for one's perception of escape (also Loewen et al., 1993). In contrast, physical features that might increase the possibility of being entrapped, such as dead ends, have a negative effect on perceived escape (e.g., Blöbaum & Hunecke, 2005). As such, adequate street lighting might point street users to important possibilities for escape, and light emitting from windows might point to social activity, and thus support in case of an emergency.

To date the effects of lighting on prospect, concealment, and escape have only been determined in quasi-experimental ways, relying on the comparison of carefully selected outdoor environments or photos. This is problematic because these outdoor environments unavoidably differ not only in terms of the quality of the lighting, but in many other physical features as well (e.g., the specific placement of trees and bushes). Few, if any, researchers have the opportunity to manipulate road lighting keeping all other physical features constant (for an exception, see Vrij & Winkel, 1991). Novel lighting technologies based on LEDs, however, offer more experimental rigor by allowing precise control of illumination output, and thus the possibility to manipulate it independently of other street, luminaire, or light characteristics.

1.4. Research goals

In the present paper, we explore where pedestrians benefit most from street lighting, and thus how light can best be distributed over the lampposts in dynamic road lighting scenarios. In particular, we test whether people feel safer with more light in their immediate surroundings, or with more light on those parts of the road that lie ahead. At the same time, we aim to confirm experimentally that the effect of lighting on perceived personal safety at night can be explained by changes in people's perceptions of prospect, escape, and concealment. By using LED-based luminaires, we manipulate light distribution independently from other physical street characteristics that might affect perceived personal safety. As far as we know, this is the first time that theories around Appleton's (1975) prospect-refuge theory are tested in a truly experimental fashion.

We present data from two experiments: with stationary and with walking participants. In Experiment 1, we focus on the safety experience of young female pedestrians, since this is one specific group of street users who might benefit most from adequate street lighting. However, research suggests that one should focus not only on biological sex, but on psychological gender as well. Blöbaum and Hunecke (2005), for example, found that more feminine women perceive a higher threat of crime when outdoors at night, as compared to women with less feminine traits. We aim to confirm this finding in Experiment 1.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-nine women participated in the experiment. The participants' mean age was 22.9 ($SD = 2.83$; range 19–30). All participants were relatively unfamiliar with the test site, with 17 of the participants (i.e., 59%) visiting the street less than once a month, and 25 (i.e., 86%) less than once a week. The test site was regarded as relatively safe, with 21 (i.e., 72%) of the participants indicating