Walking after dark - A systematic literature review of pedestrians' response to outdoor lighting

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Preface

Sustainable cities should provide for safe and healthy built environments as well as sustainable transport systems. In response to international and national environmental objectives many European cities have in recent years brought attention to the design of pedestrian environments. This also yields the presence of adequate artificial outdoor lighting.

The technological development of new light sources and innovative design of artificial lighting systems have been proposed as key tools to obtain necessary reductions in energy usage for outdoor lighting. Indeed substantial reductions have been obtained by retrofit of light sources with light emitting diodes (LED). However less is known about pedestrians' experience of pedestrian environment lit by energy efficient light sources.

This systematic literature review presents an overview of the available research on how pedestrians respond to outdoor lighting and the lit environment. Three overarching themes are identified: pedestrians' Perception of the Lit Environment, Evaluation of the Lit Environment, and Behaviour in the Lit Environment. These themes constitute an important basis for evaluations of outdoor lighting for pedestrians and will as such have implications for the development of socially sustainable and energy-efficient outdoor lighting nationally and internationally.

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Maria Johansson

Project leader

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Summary

There is a growing need for developing sustainable cities with safe, healthy living environments and energy-efficient transportation. Walking is an important part of a sustainable transportation system. So far little focus has been placed on the role of micro-level factors in the built environment, such as outdoor lighting, that may support walking among urban residents. This systematic literature review aims to present an overview of the available research on how pedestrians respond to outdoor lighting and the lit environment. Eight scientific electronic bibliographical databases and eight databases belonging to lighting-related organizations were searched. This generated 48 relevant peer-reviewed scientific papers, from a wide variety of perspectives. Through an inductive thematic analysis, three overarching themes were identified: perception of the lit environment, evaluation of the lit environment, and behaviour in the lit environment. The results indicate that both technical and human aspects should be considered, in order to find lighting solutions that create functional outdoor environments and support walking for different user groups, while minimizing energy use. However, further multidisciplinary research aimed at capturing the complexity of the human responses to outdoor lighting seems necessary.

Sammanfattning

Idag bor majoriteten av jordens befolkning i städer, och urbaniseringen fortgår. Det är därför av största vikt att utveckla hållbara städer, med hälsosamma livsmiljöer och energieffektiva transportsystem. Gående utgör en viktig del av en hållbar transportkedja. Betydelsen av mikro-faktorer i den byggda miljön, såsom utomhusbelysning, som kan bidra till att människor använder sig av gående som transportform har dock beforskats i liten utsträckning. Denna systematiska litteraturgenomgång syftar till att presentera en överblick över den tillgängliga forskningen rörande hur fotgängare upplever och responderar på utomhusbelysning. Åtta vetenskapliga elektroniska databaser och åtta databaser tillhörande belysningsorganisationer genomsöktes efter relevant litteratur. Detta genererade 48 relevanta referent-granskade artiklar, från en mängd olika perspektiv. Genom en tematisk analys identifierades tre övergripande forskningsområden: perception i den belysta miljön, värdering av den belysta miljön och beteende i den belysta miljön. Resultaten indikerar att både tekniska och mänskliga aspekter bör tas i beaktning, för att hitta energieffektiva belysningslösningar som skapar funktionella utomhusmiljöer och främjar gående för olika brukargrupper. Det är dock behov av ytterligare tvärvetenskaplig forskning för att vidarutveckla förståelsen av hur fotgängare upplever olika aspekter av utomhusbelysning.

1. Introduction

Today, the majority of the world´s population lives in cities, and further urbanization is expected globally (United Nations, 2014). This trend stresses the need for developing sustainable cities, with safe and healthy living environments, and energy-efficient transportation systems (United Nations, 2012). Walking is considered an important link in a sustainable transportation system (Rastogi, 2011) and may reduce the amount of short motor vehicle trips, thereby reducing energy usage and CO_2-emissions, decreasing noise and air pollution, and improving living conditions on a local level (Wilson, Wilson, & Krizek, 2007; Xia et al., 2015). Physical active travel such as walking also brings benefits to public health, by reducing the risk of chronic diseases such as cancer, diabetes and heart disease (World Health Organization, 2009).

A substantial amount of research has been conducted on the impact of meso-level built environment characteristics (such as density, diversity and design of the built environment) on people's travel mode choices (for a review see Ewing & Cervero, 2010). However, less focus has been placed on the influence of micro-level factors of the built environment that may be of particular importance for the choice of walking as a means of transportation (Kim, Park, & Lee, 2014; Park, Choi, & Lee, 2015).

In many parts of the world, seasonal variation in daylight hours makes pedestrians rely on outdoor lighting for ensuring functional outdoor environments for long periods of the year. During the hours of darkness, outdoor lighting contributes to visual accessibility, perceived safety, and in turn mobility. As a consequence, the presence of outdoor lighting is considered to improve neighbourhood quality (Bonaiuto, Fornara, & Bonnes, 2006) and has been shown to increase the amount of walking after dark among all age groups: adolescents (Jago, Baranowski, Zakeri, & Harris, 2005), adults (Addy et al., 2004; Eyler et al., 2002; Lee & Moudon, 2008) and elderly (Corseuil et al., 2011; Corseuil, Hallal, Corseuil, Schneider, & D'Orsi, 2012; Rosenberg, Huang, Simonovich, & Belza, 2013).

However, the benefits associated with outdoor lighting come at a cost. The annual global energy use for outdoor lighting is estimated at 218 TWh (International Energy Agency, 2006), generating both environmental and economic costs. There is potential for saving between 30-50% of the total annual lighting energy use (International Energy Agency, 2006) amongst others by updating existing outdoor lighting installations in terms of design and more energy-efficient light sources (Boyce, Fotios, & Richards, 2009;

Kuhn, Johansson, Laike, & Govén, 2013). Thus, it would be advantageous to have more nuanced understanding of how outdoor lighting, may influence pedestrians and the walkability of a street.

The aim of this literature review is to present an overview of the available research on how pedestrians respond to outdoor lighting and the lit environment. In an attempt to grasp a wide field of research encompassing multiple disciplines, a systematic approach was used.

2. Method

2.1 Review design

The design of the review procedure was based on literature on systematic reviews (Booth, Papaioannou, & Sutton, 2012; Littell & Corcoran, 2008; Petticrew & Roberts, 2006) and on the PRISMA statement (Moher, Liberati, Tetzlaff, & Altman, 2009). The outline for the review process was initially drawn up by devising a review protocol, expressing the purpose, search strategies, search terms and eligibility criteria.

2.2 Purpose

The purpose was expressed as follows: to describe and analyse the available research on the pedestrian's response to outdoor lighting and the lit environment. In order to avoid making the scope too narrow, the purpose was operationalized as follows: Pedestrian (a person of any age directly experiencing lighting and the environment); Response (perception, physiological, emotional, attitudinal, behavioural); Lighting (light sources, luminaires, lighting characteristic); and Walking.

2.3 Search strategy

The search strategy consisted of four steps and was conducted in the following order: 1. Search in electronic bibliographical databases; 2. Search in databases of relevant organizations; 3. Manual search of the past ten years of publications from relevant journals; 4. Search through the reference lists of the identified articles.

2.4 Eligibility criteria

All articles that, in some way, studied aspects of the effects of outdoor lighting on pedestrians and that were published in peer-reviewed scientific journals were eligible for inclusion in the screening process. No exclusion

criteria applied concerning date of publication, geographical or cultural aspects. The scope of the search was international but articles had to be written in English to be considered. Only primary research with direct human participation was considered.

2.5 Databases

Databases were chosen with the aim of covering a variety of research disciplines. Lund University library services were consulted for a second opinion on the search strategies and choice of databases. The following electronic bibliographical databases were searched for relevant articles and reviews: Directory of Open Access Journals, Engineering Village, Scopus, Web of Science (ISI), SocINDEX with Full Text, Psycinfo, Medline and Google Scholar. Then, based on a review of lighting-related organizations (Laike & Küller, 2012), the freely available online databases of the following organizations were searched: Centrum för Energieffektiv Belysning (CEEBEL), Commission Internationale de l'Eclairage (CIE), Illuminating Engineering Society (IES), Society of Light and Lighting (SLL), The Illuminating Engineering Institute of Japan (IEIJ), The Environmental Design Research Association (EDRA), International Association People-Environment Studies (IAPS) and Lighting Europe.

2.6 Search terms

The search terms selected were broad to reduce the chances of missing potentially relevant articles. They were divided into two groups, one containing words related to lighting and the other containing words related to the individual and walking. A Boolean search string was created in order to locate articles that contained at least one search term from both groups in either title, abstract or keywords: ('outdoor lighting' OR 'street lighting' OR 'road lighting' OR 'mesopic' OR 'high pressure sodium' OR 'LED light*' OR 'metal halide' OR 'brightness' OR 'lamp*') AND ('pedestrian*' OR 'walking' OR 'footpath*' OR 'person*' OR 'people' OR 'pavement*' OR 'bicycle' OR 'pedestrian road*'). The search string served as a template and was adapted to the different environments where the search was conducted.

2.7 Screening/selection of papers

The literature search ended June 2015. During the searches, relevant articles were identified by the title and, if needed, by reading the abstract. The search generated 306 relevant hits out of a total of 32256. After eliminating duplicates (169) and non-English articles (7), 130 relevant articles remained. Of these, 55 were

not published in peer-reviewed journals, and were therefore excluded. In the second stage of evaluation, the abstracts for the remaining 75 articles were read by two researchers who separately screened whether the abstracts contained all five aspects of the purpose: Individual, Response, Environment, Lighting and Walking. The researchers were in full agreement on the 36 articles that were deemed relevant.

In an attempt to find articles that were missed by the search string, the past ten years of publications from journals with more than one relevant hit were searched manually. Next, the reference lists were examined. Together, these steps generated 15 more hits deemed relevant. The articles were then read in chronological order. During the comprehensive reading, three articles did not, for our purpose, sufficiently report design/method and were consequently excluded from the list. The final number of articles eligible for further analysis was 48.

2.8 Thematic analysis

Next, an inductive thematic analysis was conducted (Braun & Clarke, 2006). The articles were categorized on the basis of the topics they explicitly explored. The number of categories assigned to each article varied due to their variation in scope. Next, the categories were compared for similarities and differences, and then grouped thematically. The themes were then evaluated in order to be representative of the complete set of articles.

3. Results

The identified literature (Appendix) was published in 14 different journals between 1992 and 2015. Twenty-two of the 48 articles were based on studies conducted in laboratories, while the remainder was based on field studies. The identified articles had their origins in various disciplines and illuminated the field from multiple perspectives. Approximately one-third of the articles explicitly applied a social science theoretical framework (Blöbaum & Hunecke, 2005; Boomsma & Steg, 2014; Fotios, Yang, & Uttley, 2014; Fotios, Unwin, & Farrall, 2015a; Haans & de Kort, 2012; Hanyu, 1997; Johansson, Rosén, & Küller, 2011; Johansson, Pedersen, Maleetipwan-Mattsson, Kuhn, & Laike, 2014; Kuhn et al., 2013; Loewen, Steel, & Suedfeld, 1993; Nikunen & Korpela, 2009; Nikunen, Puolakka, Rantakallio, Korpela, & Halonen, 2014; Unwin & Fotios, 2011; Viliunas et al., 2014) while the rest employed a lighting-oriented approach or were less clear in their theoretical standpoint. Only two articles was primarily qualitative (Fotios et al., 2015a; Unwin & Fotios, 2011), while the rest used quantitative methods and analyses. Eleven articles only reported descriptive statistics

while the others applied inferential statistics. The median number of participants was 36, and one-fifth of the studies had 20 or less participants. Fifty-four percent of the articles reported from which population the participants were recruited, and of these articles 50 percent used student populations.

The thematic analysis generated three overarching themes based on 14 categories (Figure 1). The first theme, labelled Perception of the Lit Environment, deals with how light is perceived differently depending on individual factors, such as age and eyesight, and on the various characteristics of the light source. The second and third themes cover the topics of how the individual reacts to the perceived environment; either psychologically, labelled Evaluation of the Lit Environment, or physically, labelled Behaviour in the Lit Environment.

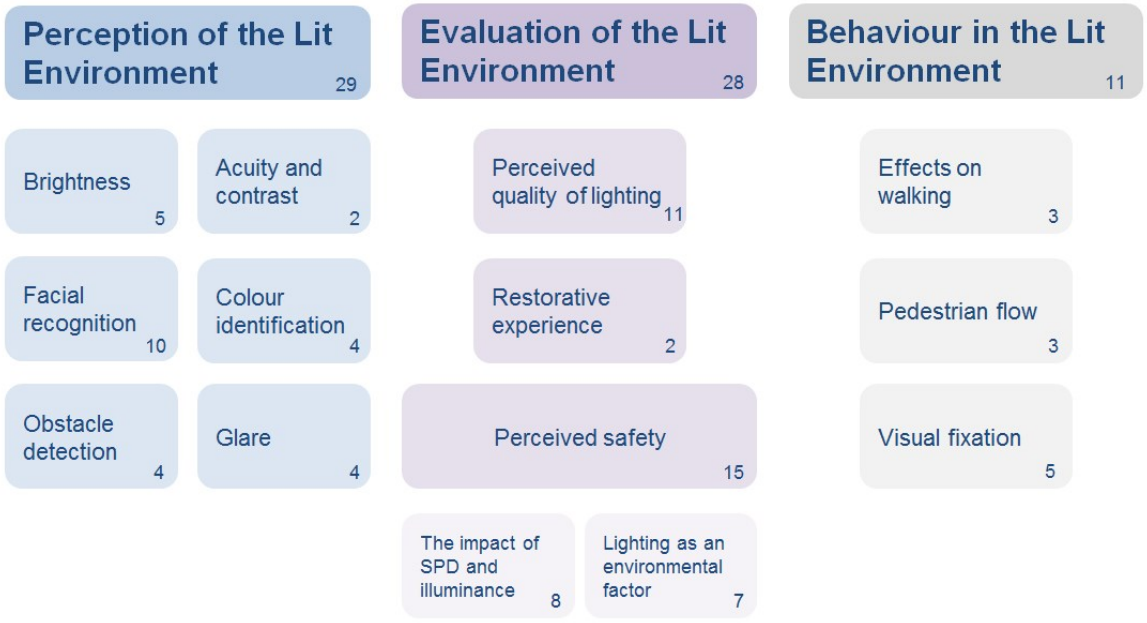

Figure 1. Overarching themes, corresponding categories and number of articles within each category.

3.1 Perception of the lit environment

Nearly 43 percent of the articles were categorized as regarding the pedestrian's perception of lighting and the lit environment. Several topics have been explored in this field, ranging from perception of brightness and colour to visual tasks such as facial recognition and obstacle detection. The outdoor environment after dark is characterized by mesopic conditions, which serves as common ground for the studies related to perception of the lit environment.

3.1.1 Brightness

The perceived brightness under mesopic conditions has been researched both in the laboratory and in field settings. The laboratory studies have used various techniques, for example brightness matching, brightness discrimination and descriptive scales, in order to compare lamps with different spectral power distribution (SPD). The findings from the laboratory studies are unanimous, indicating that perceived brightness is dependent on SPD and that, at equal illuminance, lamps with whiter light (greater scotopic/photopic, S/P-ratio) are perceived brighter.

A study by Fotios and Cheal (2007a) examined the importance of SPD for brightness by comparing high-pressure sodium (HPS), two types of ceramic metal halide (CMH) and a compact fluorescent light (CFL). The results from side-by-side comparison showed that the whiter lamps were perceived brighter at equal illuminance and that they were perceived as equally bright at an illuminance about 70% of the illuminance of the HPS lamp. By using semantic scales and sequential rating, they also concluded that the whiter lights are perceived brighter and clearer than HPS. Similar results were found by Rea and colleagues (Rea, Radetsky, & Bullough, 2011) who showed that CMH lamps were perceived brighter at equal illuminance and perceived equally bright as HPS at 74-80% of the illuminance of the HPS lamp.

In another study, Fotios and Cheal (2011a) compared HPS, CDM-T (CMH), CFL, CPO (CMH) and light-emitting diode (LED) lamps by both brightness matching and brightness discrimination. They found that the results of the two tests were in accordance and that LED (S/P: 2.8), CDM-T (S/P: 1.66) and CFL lamps (S/P: 1.86) were perceived brighter than CPO (S/P: 1.25), which in turn was perceived brighter than HPS (S/P: 0.48). In this study the CMH/HPS illuminance ratio was 0.78.

The applicability of these results in real-world settings has been tested in field studies (Knight, 2010; Rea, Bullough, & Akashi, 2009). In a study carried out in residential areas in Spain, the United Kingdom and the Netherlands, Knight (2010) investigated the effect of lamp spectrum on the perception of brightness, safety and comfort, as well as on pedestrians' ability to recognize faces. The lighting was changed either from HPS (SON, Correlated Colour Temperature, CCT≈2000K) to one of the two kinds of CMH (CDO, CCT=2800K; CDM, CCT=4200K), or from CMH to HPS. In the UK, brightness ratings showed significant improvements when changing to CMH lamps, and significant decline when changing to HPS. In all countries and test locations, the CMH lamps were rated brighter, when compared to a previous HPS installation.

Rea et al. (2009) compared HPS and CMH lamps in terms of perceived brightness, safety, acceptability for social interaction, and eyewitness identification. The study was located in a park, and the participants were placed in the middle of a street between two luminaires containing either a HPS or CMH lamp. The respondents were asked under which lighting the objects and the street appeared brighter, for illuminances ranging from 5 to 15 lx. At equal illuminances, the ratings were always significantly higher for CHM, regardless of illuminance level.

3.1.2 Facial recognition

Facial recognition is considered to be an important visual task for pedestrians after dark. It has been investigated both in laboratory settings (Dong, Fotios, & Lin, 2014; Fotios, Uttley, Cheal, & Hara, 2015b; Iwata & Uchida, 2011; Kohko, Kawakami, & Nakamura, 2008) and in the field (Johansson et al., 2011; Knight, 2010; Kuhn et al., 2013; Lin & Fotios, 2015; Rea et al., 2009; Yao, Sun, & Lin, 2009). The studies have used photographs, dummies or assistants as targets that should be recognized by the respondents. A common technique has been to measure the distance at which the respondents are certain of the gender, can guess the identity or make out facial features. Also, self-reported ability of facial recognition has been employed as a part of a composite visual accessibility scale (Johansson et al., 2011; Kuhn et al., 2013). Facial recognition has been tested under different light sources, illuminance levels and observation durations but also as a means to evaluate the impact of glare.

The findings are not corresponding when it comes to the importance of SPD for facial recognition. Some studies (Knight, 2010; Yao et al., 2009) find significant differences between lamps of different SPD, while other studies (Fotios et al., 2015b; Rea et al., 2009; Yao et al., 2009) do not. It is argued that, an effect of SPD is more likely when the task is more difficult (e.g. at longer distances or shorter durations) (Lin & Fotios, 2015).

Dong et al. (2014) explored task difficulty in relation to facial recognition by using both matching and identification tasks, for different luminances and observation durations. They concluded that identification was more difficult than matching and that both duration and luminance mattered for the recognition probability. For being able to judge the emotion of a facial expression at a distance of 10 meters, Fotios et al. (2015b) recommend a minimum face luminance above 1 cd/m^2.

3.1.3 Obstacle detection

Two studies by Fotios and Cheal (2009, 2013) investigated the importance of the illumination level and light source for obstacle detection. They used specially designed apparatus to simulate detection of obstacles on the ground by raising objects within the apparatus at a distance close to the eye. Illuminance, age and SPD were found to affect obstacle detection (Fotios & Cheal, 2009). There was an inverse relationship between illuminance level and the height needed in order to detect an obstacle, and at 0.2 lx the younger participants detected significantly lower obstacles. Also, at 0.2 lx, CDM (S/P: 1.77) had lower detection height than CPO (S/P: 1.22), which in turn had lower detection height than HPS (S/P: 0.57). For higher illuminance levels (2 & 20 lx) the differences due to age and SPD were not significant. Using a similar method as in their previous study, Fotios and Cheal (2013) set out to test the relationship between obstacle detection and illuminance level by testing one lamp (HPS; CCT: 2000; Colour Rendering Index, CRI: 25; S/P: 0.57) at five levels of illuminance (0.20, 0.63, 2.00, 6.32 & 20.00 lx). Their results supported their previous findings and at higher detection rates a plateau-escarpment relationship became apparent, with a break of slope at about 2 lx. Obstacle detection is also part of the composite visual accessibility scale mentioned previously (Johansson et al., 2011; Kuhn et al., 2013).

3.1.4 Acuity and contrast

Acuity and contrast threshold have been researched in the laboratory in relation to illuminance level and light source (Fotios & Cheal, 2007b, 2011b). Fotios and Cheal (2007b) found that foveal visual acuity and contrast sensitivity significantly decreased with lower illuminance levels. For achromatic acuity and contrast, there were no significant differences for the different light sources. However, for chromatic acuity there was a significant effect of lamp type that interacted with the colour of the target (red: MH, green: CFL and blue: HPS). Age was also significant; older participants scored lower than the younger ones. The second study by Fotios and Cheal (2011b) produced some unexpected results. They found that SPD significantly affects achromatic visual acuity and that there seemed to be a reverse relationship between acuity and S/P ratio. LED lighting (S/P: 2.8) performed significantly worse than all other light sources, especially compared to the HPS lamp. The authors concluded that it was an unexpected result, and that further studies were needed to investigate whether the results were coincidental or represented a visual phenomenon.

3.1.5 Colour identification

Several studies have evaluated the preferred appearance of the colour of objects and the ability to correctly identify the natural colour under different light sources (Fotios & Cheal, 2007b, 2011b; Kuhn et al., 2013; Yao et al., 2009). They have been conducted both in the laboratory using side-by-side booths and in field settings, such as a residential area and urban streets. In all studies comparing CMH and HPS, CMH lamps performed better. Fotios and Cheal (2007b) compared the ability to correctly identify colours for five different light sources at 2 lx and at 15 lx. They found a trend for colour identification accuracy to decrease at lower illuminances with significant differences for the HPS, CFL, MH lamps. However, under the LPS and a second MH lamp, the differences were not significant.

Due to the variation in SPD of different LED light sources, there are mixed results for comparisons involving LED (Fotios & Cheal, 2011b; Kuhn et al., 2013).

3.1.6 Glare

Four laboratory studies have evaluated the influence of glare on pedestrian perception and performance in the lit environment. Kohko et al. (2008) investigated facial recognition in a laboratory in order to quantify the loss of perceived facial luminance caused by glare. They found that the face luminance required for facial recognition increased as the equivalent veiling luminance increased, and they suggested that in order to estimate the probability of facial recognition, both background luminance and equivalent veiling luminance should be considered simultaneously. Davoudian, Raynham and Barret (2014) directly measured the scattered light in the eyes of the participants, thus being able to calculate the veiling luminance on an individual level. They found that the increase in veiling luminance caused by glare led to a need for a higher luminance contrasts between the background and the objects the participants were asked to identify. Zhu et al. (2013) evaluated discomfort glare from LED road lighting and found that both the subjective discomfort glare and the change in pupil diameter depended on the surface luminance of the light source, the CRI and the angle to the glare source. Brighter light sources with higher CRI at a smaller angle were considered more glaring (Zhu et al., 2013).

Iwata and Uchida (2011) evaluated performance and subjective impressions of the environment for two types of luminaires with different glaring properties. They evaluated many of the visual tasks described above, but in relation to glare. They found that at equal vertical illumination (1.3 lx) the cut-off luminaire with less glare resulted in better performance for facial recognition, obstacle detection, visual acuity and, for participants with

simulated senile cataract, also colour recognition. However, at the midpoint between the luminaires, the vertical illuminance differences were of such magnitude (midpoint vertical illuminance: 0.3lx for cut-off and 2.9 lx for glaring luminaire) that they compensated for the glare effect and reversed the results.

3.2 Evaluation of the lit environment

Approximately 41 percent of the articles were categorized as considering how people subjectively evaluate and experience the lit environment. While different aspects of this evaluation have been studied, the major topic is perceived safety, also called reassurance or perceived danger.

3.2.1 Perceived safety

Impact of SPD and illuminance on perceived safety: One approach to the study of the effect of outdoor lighting on perceived safety is to investigate the impact of light sources with different spectral power distributions. This has been done in the field either by evaluating relighting in residential areas or by conducting small-scale quasi-experiments in field settings. Results from studies evaluating relighting suggest that light sources with whiter light have a positive impact on perceived safety (Herbert & Davidson, 1994; Knight, 2010; Nair, McNair, & Ditton, 1997; Painter, 1994, 1996), as well as a direct impact on actual crime rate (Painter, 1994, 1996). After asking participants to compare CMH lighting to a previous installation of HPS, Knight (2010) found that, in all countries and locations of the study, the participants reported feeling significantly safer with CMH lighting. Also, when the perceived safety is already high prior to re-lighting, retrofitting with LED does not appear to affect the perception of safety negatively (Kuhn et al., 2013).

The results from experiments comparing HPS and CMH are not in full agreement regarding the importance of white light for perceived safety (Boyce, Eklund, Hamilton, & Bruno, 2000; Rea et al., 2009). Rea et al. (2009) showed that at equal illuminance, or with CMH at higher illuminance, people felt safer with the CMH condition than HPS. With HPS at higher illuminance (15 lx compared to CMH at 5 lx), they found no significant differences in the feelings of safety.

Boyce et al. (2000), on the other hand, emphasize the importance of illuminance over lamp spectrum for the feelings of safety. In their study they asked participants to rank parking lots with different lighting in terms of how safe they would feel walking alone in the parking lot at night, which light people would look the best under, and which light would make it easiest to identify an approaching person. The parking lots were lit by either two 250 W HPS lamps, two 250 W CMH lamps or two 400 W HPS lamps. The respondents ranked

the parking lots both wearing and not wearing grey wraparound glasses with a transmittance of 0.1, used in order to create a mesopic adaption state. They found that the HPS lamps were preferred over the CMH lamp, both with and without the wraparound glasses. However, the results are hard to interpret since the lamps were compared on basis of wattage and did not have equal illuminance, and because the differences in rankings were not statistically analysed.

Lighting as an environmental factor influencing perceived safety: Another take on perceived safety has its starting point in Appleton's (1975) prospect-refuge theory. Appleton suggested that evolution makes people aesthetically prefer locations where they have overview (prospect) while they themselves cannot be seen (refuge). Fisher and Nasar (1992) further developed the theory in relation to the influence of environmental factors on perceived safety in urban areas. They found that people assess places as less safe if the environment provides refuge for potential criminals, while limiting prospect and possibilities to escape. These environmental factors have also been investigated in relation to lighting and perceived safety (Blöbaum & Hunecke, 2005; Boomsma & Steg, 2014; Haans & de Kort, 2012; Loewen et al., 1993). Although the studies interpret Appleton (1975) and Fisher and Nasar (1992) slightly differently in terms of environmental factors (Blöbaum et al.: Lighting/Prospect, Concealment & Entrapment; Boomsma & Steg: Lighting & Entrapment; Haans et al.: Lighting, Prospect, Concealment & Escape; Loewen et al.: Light, Prospect & Refuge), all studies support the importance of the environmental factors and lighting for perceived safety. According to Loewen et al. (1993), the presence of light is the most important factor, while others (Blöbaum & Hunecke, 2005; Haans & de Kort, 2012) find significant interaction effects. Lighting seems especially important for perceived safety when the environment is deemed to have low level of entrapment (Blöbaum & Hunecke, 2005) and when the lighting is focused on the nearby surroundings. It is suggested that this may affect the level of prospect positively and thereby indirectly the perceived safety (Haans & de Kort, 2012).

The extent to which road lighting contributes to improved reassurance has also been investigated through interview studies (Fotios et al., 2015a; Unwin & Fotios, 2011). In a pilot study, Unwin and Fotios (2011) found that lighting and environmental factors made up approximately half of the stated reasons for wanting or not wanting to walk down a street at night-time. In a follow-up study lighting was mentioned by 87% of the participants as a reason for feeling reassured when walking after dark (Fotios et al., 2015a).

A study by Muramatsu et al. (2001) indicates that lighting on private property, such as gate and entryway lights, has a positive influence on perceived safety on pedestrian streets. These researchers suggest that it

enhances the evaluation of the environment and that decorative lights in particular make people attribute positive characteristics to the residents of the area, which would indirectly influence the perceived safety.

3.2.2 Perceived quality of lighting

In the identified literature, subjective assessment of lighting quality has been conceptualized in different ways. Shikakura et al. (1992) propose that the subjective impressions could be factorized into two first-order factors, brightness and uniformity, and one composite factor related to comfort, safety and familiarity. In contrast, Johansson et al. (2011) and Kuhn et al. (2013) use the dimensions proposed by Küller and Wetterberg (1993, 1996), who suggest that subjective impressions can be described by the dimensions of brightness and hedonic tone. This concept has been further developed in relation to outdoor lighting through the development of the Perception of Outdoor Lighting Quality scale (Johansson et al., 2014), which consists of the two categories; Perceived Strength Quality and Perceived Comfort Quality.

Another approach was taken by Boyce et al. (2000), who evaluated the lighting quality by using seven scales that were found to correlate across 25 different sites. Their conclusion was that good lighting was perceived as being bright, even, comfortable, extensive in area and well matched to the site.

Subjective lighting assessment has been investigated in relation to various topics. Shikakura et al. (1992) investigated the influence of luminaire installation design and luminous intensity distribution on the impression of the light. A narrower luminance distribution reduced uniformity, an increase in installation height reduced brightness, and closer distance between luminaires resulted in a more uniform and bright impression. Viliūnas et al. (2014) explored the subjective evaluation of luminance distribution and concluded that the luminous flux of the light source closest to the pedestrian was the one most important both for the subjective well-being and for the evaluation of the lit environment.

In their study of visibility and subjective impressions of the lit environment, Iwata and Uchida (2011) asked the participants to rate their experience of walking a distance under different luminaires. Luminaires with upward light output were perceived as brighter and brought a higher degree of satisfaction while, at the same time, being more glaring. The evaluation of the atmosphere was similar for the luminaires with and without upward light output, but these results were not validated statistically.

Hanyu (1997) set out to evaluate the affective response to the experience of visual properties of residential areas after dark. The study showed that non-uniform lighting was correlated to arousal and that brightness was correlated with feeling active, interested and safe.

Other studies examined the perceived lighting quality for pedestrians on an urban footpath and in a retro-fitted residential area respectively. Johansson et al. (2011) found that the brightness and hedonic tone dimensions could predict perceived danger, whereas the brightness dimension also predicted perceived accessibility. Kuhn et al. (2013) used the brightness and hedonic tone dimensions as well as a softness factor to compare the effect of retrofitting with LED on the subjective assessment of lighting quality. The study showed that retro-fitting with LED from HPS improved the perceived brightness and softness, while retrofitting with LED from HPM improved all dimensions.

Others have used questionnaires with single items attempting to capture different dimensions of the subjective lighting experience in order to compare light sources (Juntunen et al., 2015; Kostic & Djokic, 2014; Paakkinen, 2014). Kostic and Djokic (2014) compared CMH and LED on a pedestrian path within a park, and found that CMH was rated significantly better on all aspects and was preferred by more than 84 percent of the respondents. The differences in the other two studies were not analysed statistically and thus hard to interpret.

3.2.3 Restorative experience

Another aspect of the evaluation of the lit environment lighting is the potential for restorative experiences. Nikunen and Korpela (2009) investigated the extent to which the restorative experience is influenced by lighting distribution, by contrasting images with light focused on greenery with images where the light was focused on parking lots and roads. People were found to rate their restorative experience significantly higher when the light was focused on the greenery. In another study, Nikunen et al. (2014) investigated whether different lighting qualities were related to the components of the Attention Restoration Theory. They suggested that the way people perceive lighting in terms of pleasantness, safety, colour quality, brightness and glare is correlated with the recovery of the capacity to focus attention.

3.3 Behaviour in the lit environment

Only about 16 percent of the articles were categorized as regarding behaviour in the lit environment. The impact of lighting manifests itself in overt behaviour. Studies show that presence of street lighting, as well as

lack of lighting, may have tangible effects on pedestrian behaviour. Lamps with whiter light and better colour rendering appear to increase pedestrian flow on the streets where lighting has been replaced (Herbert & Davidson, 1994; Painter, 1994, 1996). Painter (1994, 1996) carried out a pedestrian count, one week before and six weeks after the street lighting had been changed from low-pressure sodium to high-pressure sodium, and found an increase in pedestrian flow ranging from 34 to 101 percent. While Herbert and Davidsson (1994) did not find consistent overall changes of pedestrian flow in two cities after changing the lighting from low-pressure sodium to high-pressure sodium, for both cities the number of pedestrians using the streets after 9 pm seemed to increase.

Results from a laboratory study suggest that insufficient lighting decreases the step rate of older people and makes them look at the floor more, compared to brighter conditions (Itoh, 2006). In a later study, this decrease in walking speed was replicated for a group of younger participants, however no significant effect was found for an older group (Choi, Kang, Shin, & Tack, 2014). Sufficient lighting also seems important for reducing the risk of falling accidents. In a study conducted in an accident and emergency department in the UK, it was reported that 42% of the patients who suffered outdoor fall accidents after dark felt that the street lighting had been inadequate (Fothergill, O'Driscoll, & Hashemi, 1995).

Several studies have used eye-tracking equipment to research visual fixations, in order to identify the critical visual tasks of pedestrians after dark (Davoudian & Raynham, 2012; Fotios et al., 2014; Fotios, Yang, & Cheal, 2015c; Fotios, Uttley, & Yang, 2015d; Luo, Puolakka, Zhang, Yang, & Halonen, 2013). Davoudian and Raynham (2012) found that people looked at the pavement approximately half of the time, while only 3.5% of the total time was spent looking at other people. However, the low proportion of fixations on pedestrians might have been due to the low number of pedestrians compared to other objects.

In order to identify the objects that capture the attention of pedestrians, Fotios, Uttley, Cheal and Hara (2015d) used a dual-task approach. The participants were asked to press a button when they heard a sound, while simultaneously walking outdoors wearing eye-tracking equipment. Visual fixations were deemed critical if the response to the auditory task was delayed, thus indicating cognitive processing of the visual stimulus. They found that the critical fixations mainly consisted of fixations on the near path and on distant pedestrians. For pedestrians there was a significant difference in fixations between day and night. This appeared to be due to differences in stimulus frequency, and when taking the difference in number of pedestrians for the two conditions into account the probability of looking at the pedestrians were equal for night and day (Fotios et

al., 2015c). Fotios, Yang and Uttley (2014) found the overall distance for viewing other pedestrians to be 10.3 meters, with significantly shorter differences after dark. It is unclear if that results from differences in preference or if it comes from worse visual conditions.

4. Discussion

This review shows that the scientific research on how pedestrians respond to outdoor lighting and to the lit environment is limited. Despite the broad operationalization of purpose and the wide scope of the search, surprisingly few articles relevant for the understanding of how outdoor lighting may support good walking conditions in the built environment were identified. It appears that, in the research on outdoor lighting, the human responses have largely been overlooked in favour of more salient technical aspects.

The thematic analysis of the identified articles produced three overarching themes: perception of the lit environment, evaluation of the lit environment and behaviour in the lit environment. The themes represent the major approaches to the exploration of the impact of outdoor lighting on walking after dark. The number of categorized articles was unevenly distributed, with skewness towards perception of the lit environment and evaluation of the lit environment. The behavioural aspects have merely been touched upon, and there is much left to explore when it comes to how different light sources and lighting design might affect overt behaviour. This highlights the potential of merging lighting research with the research on the influence of the built environment characteristics on the choice of walking as a means of transportation.

Due to the high proportion of laboratory studies, small population sizes and little information regarding the background of the participants, the ecological validity and the generalizability of many of the findings might be questioned. About one-fifth of the present studies had less than 20 participants, which may have implications for the statistical power and analyses. The use of larger samples would address these issues and benefit the field by improving the replicability of findings and reducing the risk of false positives (Fraley & Vazire, 2014). The field settings seem to reflect areas of relevance for pedestrians in the urban space. However, the participants are predominantly students, and few studies have considered elderly people, the visually impaired or other vulnerable groups. It would be advantageous if future studies recruited participants from a wider population in order to identify outdoor lighting solutions better suited to the needs of different user groups.

Another drawback is the frequent lack of an explicit theoretical starting point, which makes it harder to evaluate and interpret the findings. Only one-third of the articles address the human response to outdoor lighting by applying a social science theoretical framework. The majority of the articles seem to treat the human aspects somewhat superficially, and these aspects receive less attention than the technical aspects. The inverse situation may also be the case; some of the articles approaching the topic from the social science perspective do not describe the technical characteristics of the lighting. This indicates that there is a need for a more interdisciplinary approach to the field, in order to better capture the complexity of the human responses to outdoor lighting.

Some results that apply to the design of outdoor lighting for pedestrians seem however stable across studies. The by far the most frequently researched topic is the relationship between outdoor lighting and perceived safety. The identified literature concludes that lighting can be seen as an important environmental factor that influences the perception of safety (Blöbaum & Hunecke, 2005; Boomsma & Steg, 2014; Haans & de Kort, 2012; Loewen et al., 1993). The light source is clearly shown to be important, and light sources with whiter light appear to have a positive effect on perceived safety (Herbert & Davidson, 1994; Knight, 2010; Nair et al., 1997; Painter, 1994, 1996). There is however a lack of articles with a holistic approach to lighting for pedestrians. As an example, no articles were found that bridged the gap between the importance of the light source and of lighting as an environmental design factor.

The superiority under mesopic conditions of lamps with greater S/P-ratio is reflected in the results of several studies relating both to pedestrians' perception of the light and their performance of important tasks. For instance, the findings from both laboratory and field studies are in agreement and demonstrate that lamps with higher S/P ratio are perceived as brighter (Fotios & Cheal, 2007a, 2011a; Knight, 2010; Rea et al., 2009; Rea et al., 2011). This may explain the effect of SPD on facial recognition, where some studies show that light sources with greater S/P ratio make it possible to recognize faces at longer distances (Knight, 2010; Yao et al., 2009).

SPD is also shown to be important for obstacle detection, at least at illuminances as low as 0.2 lx, where lamps with greater S/P ratio enable detection of lower obstacles (Fotios & Cheal, 2009, 2013). There are also studies indicating that changing the outdoor lighting to lamps with greater S/P ratio increases the number of pedestrians using the street (Painter, 1994, 1996). The literature is less coherent on subjective assessment of lighting quality, and different approaches are taken. Common lighting characteristics of interest are brightness,

uniformity and comfort (Johansson et al., 2011; Johansson et al., 2014; Kuhn et al., 2013; Shikakura et al., 1992).

In further research it would be desirable to design studies that use a strong theoretical approach (Blöbaum & Hunecke, 2005), while also applying both technical and observer-based environmental assessment (Johansson et al., 2014). Using control or reference groups (Knight, 2010) and long-term follow-ups (Painter, 1996) would be a way to strengthen the design of future studies.

The scarcity of findings may reflect the limitations of this review in terms of, for instance, the eligibility criteria. Including articles written in other languages than English may have produced a different picture. Also, in the screening process, about one-third of the identified articles were excluded due to lack of peer-review. Much of the research on human responses to outdoor lighting seems to take place, or at least is published, outside of the scientific community. However, due to the multi-disciplinary character of the field, the peer-review criterion was deemed to be the best way to guarantee the scientific soundness of the included articles. Our hope is that this review will serve as a starting point for an attempt to incorporate knowledge from the lighting field into the fields of urban planning, furthering the understanding of the relationship between the micro-level factors of the built environment, travel mode choices and walkability. This could lead to an improved accessibility of the public space after dark for all users and encourage physical activity and non-motorized transportation, thereby contributing to the development of a more sustainable society.

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APPENDIX

Identified literature in chronological order

Publication year	Author(s) and title	Journal	Aim	Setting	Population
1992	Shikakura, T., Kikuchi, S., Tanaka T. & Furuta, Y. Psychological evaluation of outdoor pedestrian lighting based on rendered images by computer graphics	Journal of the Illuminating Engineering Institute of Japan	To evaluate the subjective impression of the illuminated environment	Laboratory	Not reported
1993	Loewen, L. J., Steel, G. D. & Suedfeld, P. Perceived safety from crime in the urban environment	Journal of Environmental Psychology	To test various aspects of Appleton's prospect and refuge theory in relation to perceived safety after dark	Laboratory	Undergraduate students
1994	Herbert, D. & Davidson, N. Modifying the built environment: The impact of improved street lighting	Geoforum	To explore the influence of street lighting on crime and fear of crime	Residential streets	Residents
1994	Painter, K. The impact of street lighting on crime, fear and pedestrian street use	Security Journal	To assess the impact of lighting improvements on crime and fear of crime	Urban streets	Pedestrians
1995	Fothergill, J., O´Driscoll, D. & Hashemi, K. The role of environmental factors in causing injury through falls in public places	Ergonomics	To investigate the role of outdoor lighting in relation to fall accidents	Public places	Patients

1996	Painter, K. The influence of street lighting improvements on crime, fear and pedestrian street use, after dark	Landscape and Urban Planning	To examine the impact of street lighting improvements on crime and fear of crime	Urban streets	Pedestrians and nearby residents
1997	Hanyu, K. Visual properties and affective appraisals in residential areas after dark	Journal of Environmental Psychology	To reveal relationships between visual properties and affective appraisals	Laboratory	Students
1997	Nair, G., McNair, D. G, & Ditton, J. Street lighting: Unexpected benefits to young pedestrians from improvement	Lighting Research and Technology	To research the effect of street lighting on pedestrian fear of crime through a relighting project	Carriageway in a park	Pedestrians
2000	Boyce, P. R., Eklund, N. H., Hamilton, B. J. & Bruno, L. D. Perceptions of safety at night in different lighting conditions	Lighting Research and Technology	To investigate how much light is needed to provide a perception of safety at night	Urban streets and parking lots	Lighting professionals and people hired from an employment agency
2001	Muramatsu, R. Nakamura, Y., Nakajima, S. & Kobayashi, S. Effects of house exterior lighting on the evaluation of lighting environment on nighttime residential streets	Journal of Light & Visual Environment	To research whether private property lighting affects impressions of streets at night	Residential streets	Non-residents (students and workers)
2005	Blöbaum, A. & Hunecke, M. Perceived danger in urban public space. The impacts of physical features and personal factors	Environment and Behaviour	To analyse the influence of lighting and various physical features on perceived danger	University campus	Students

2006	Itoh, N. Visual guidance of walking: Effects of illumination level and edge emphasis	Gerontechnology	To investigate the importance of lighting for walking speed and visual orientation	Laboratory	Not reported
2007	Fotios, S. A. & Cheal, C. Lighting for subsidiary streets: Investigation of lamps of different SPD. Part 1 - Visual performance	Lighting Research and Technology	To test the effects of spectral power distribution on perceived brightness and on-axis visual performance	Laboratory	Not reported
2007	Fotios, S. A. & Cheal, C. Lighting for subsidiary streets: Investigation of lamps of different SPD. Part 2 - Brightness	Lighting Research and Technology	To examine whether lamps of different spectral power distribution have a different appearance in terms of brightness. To test whether the results can be predicted by models of mesopic photometry	Laboratory	Not reported
2008	Kohko, S., Kawakami, K. & Nakamura, Y. A Study on affects of veiling luminance on pedestrian visibility	Journal of Light & Visual Environment	To quantify the loss caused by glare in the luminance required to identify a person	Laboratory	Not reported
2009	Fotios, S. A. & Cheal, C. Obstacle detection: A pilot study investigating the effects of lamp type, illuminance and age	Lighting Research and Technology	To study the effects of light source, illuminance and observer's age on the ability to detect obstacles in peripheral vision under mesopic conditions	Laboratory	Not reported
2009	Nikunen, H. J. & Korpela, K., M. Restorative lighting environments - Does the focus of light have an effect on restorative experiences?	Journal of Light & Visual Environment	To test whether focusing light on vegetation compared to parking lots affects restorative experiences	Laboratory	Students and university staff

2009	Rea, M., Bullough, M & Akashi, Y. Several views of metal halide and high-pressure sodium lighting for outdoor applications	Lighting Research and Technology	To compare metal halide and high-pressure sodium lamps in terms of perceived brightness, safety, acceptability for social interaction, facial recognition and eyewitness identification	Street	Not reported
2009	Yao, Q. Sun, Y. & Lin, Y. Research on facial recognition and colour identification under CMH and HPS lamps for road lighting	LEUKOS - Journal of Illuminating Engineering Society of North America	To compare the performance of CMH and HPS lamps in terms of facial recognition and colour identification	Streets	Not reported
2010	Knight, C. Field surveys of the effect of lamp spectrum on the perception of safety and comfort at night	Lighting Research and Technology	To investigate whether the results from laboratory studies regarding lamp spectrum and perceived safety and brightness are transferable to actual residential streets	Residential streets	Residents
2011	Fotios, S. A. & Cheal, C. Predicting lamp spectrum effects at mesopic levels. Part 1: Spatial brightness	Lighting Research and Technology	To test metrics for predicting spatial brightness at mesopic levels for lamps of different spectral power distribution	Laboratory	Not reported
2011	Fotios, S. A. & Cheal, C. Predicting lamp spectrum effects at mesopic levels. Part 2: Preferred appearance and visual acuity	Lighting Research and Technology	To evaluate how lamp spectrum affects visual acuity and the preferred appearance of hands, colour arrays and an illuminated space	Laboratory	Not reported

2011	Iwata, M. & Uchida, S. Experiment to evaluate visibility with street luminaires with different upward light output ratios and the use of calculated veiling luminance to determine contrast performance	Journal of Light & Visual Environment	To evaluate the effect of glare on visibility and impressions of the street, for young and elderly people	Laboratory	Students
2011	Johansson, M., Rosén, M. & Küller, R. Individual factors influencing the assessment of the outdoor lighting of an urban footpath	Lighting Research and Technology	To investigate possible predictors of perceived visual accessibility and perceived danger for pedestrians on an urban footpath after dark	Foot and cycle path	Visually impaired, elderly people and young women
2011	Rea, M. S., Radetsky, L. C. & Bullough, J. D. Toward a model of outdoor lighting scene brightness	Lighting Research and Technology	To establish a provisional spectral weighting function for the apparent brightness of illuminated outdoor scenes	Laboratory	Not reported
2011	Unwin, J. & Fotios, S. A. Does lighting contribute to the reassurance of pedestrians at night-time in residential roads?	Journal of Lighting Engineering	To examine the effects of street lighting on pedestrian reassurance in residential streets	Laboratory	Not reported
2012	Davoudian, N. & Raynham, P. What do pedestrians look at at night?	Lighting Research and Technology	To identify the principal visual tasks of pedestrians at night	Residential streets	Not reported
2012	Haans, A. & de Kort, Y. A. W. Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect , concealment and escape	Journal of Environmental Psychology	To explore whether pedestrians feel safer with lighting in their immediate surroundings compared to lighting of the road ahead	University campus	Young women and undergraduate students

2013	Fotios, S. A. & Cheal, C. Using obstacle detection to identify appropriate illuminances for lighting in residential roads	Lighting Research and Technology	To verify the relationship between illuminance level and obstacle detection found in a previous study. To identify illuminance level needed for a 95% probability of obstacle detection in the field	Laboratory	Not reported
2013	Kuhn, L., Johansson, M., Laike, T. & Govén, T. Residents' perceptions following retrofitting of residential area outdoor lighting with LEDs	Lighting Research and Technology	To compare conventional lighting to LED in terms of perceived lighting quality, visual accessibility and danger. To evaluate potential energy savings	Residential areas	Residents
2013	Luo, W., Puolakka, M., Zhang, Q.Yang, C. & Halonen, L. Pedestrian way lighting: User preferences and eye fixation measurements	Journal of Lighting Engineering	To explore the relationship between lighting conditions, user preferences and eye-fixation	Urban streets	Not reported
2013	Zhu, X., Deng, S., Zhang, M., Cheng, W., Heynderickx, I. Perception study of discomfort glare from LED road lighting	Light & Engineering	To evaluate how LEDs with different CRI and illuminance influence discomfort glare	Laboratory	Not reported

2014	Boomsma, C. & Steg, L. Feeling safe in the dark: Examining the effect of entrapment, lighting levels and gender on feelings of safety and lighting policy acceptability	Environment and Behaviour	To examine the extent to which physical and individual factors affect feelings of safety	Laboratory	Students
2014	Choi, J.-S., Kang, D.-W., Shin, Y.-H. & Tack, G.-R. Differences in gait pattern between the elderly and the young during level walking under low illumination	Acta of Bioengineering and Biomechanics	To compare changes in gait pattern between the elderly and young under low illumination	Laboratory	Not reported
2014	Davoudian, N., Raynham, P. & Barrett, E. Disability glare: A study in simulated road lighting conditions	Lighting Research and Technology	Examine the effect of glare under normal street lighting conditions	Laboratory	Not reported
2014*	Dong, M., Fotios, S. & Lin, Y. The influence of luminance, observation duration and procedure on the recognition of pedestrians' faces	Lighting Research and Technology	To explore the influence of duration, luminance and task for the difficulty of facial recognition	Laboratory	Students and university staff
2014*	Fotios, S., Yang, B. & Uttley, J. Observing other pedestrians: Investigating the typical distance and duration of fixation	Lighting Research and Technology	Investigating at what distance and duration pedestrians typically fixate on other pedestrians	University campus	Not reported
2014	Johansson, M., Pedersen, E., Maleetipwan-Mattsson, P., Kuhn, L. & Laike, T. Perceived outdoor lighting quality (POLQ): A lighting assessment tool	Journal of Environmental Psychology	To develop a tool suitable for measuring qualities of outdoor lighting	Residential streets	Residents, university staff and students

2014	Kostic, A., Djokic, L. Subjective impressions under LED and metal halide lighting	Lighting Research and Technology	To compare MH and LED lighting installations at comparable illuminance levels, CCT and CRI	Pedestrian path in a park	Students
2014	Nikunen, H., Poulakka, M., Rantakallio, A., Korpela K. & Halonen, L. - Perceived restorativeness and walkway lighting in near-home environments	Lighting Research and Technology	To investigate the influence of different lighting qualities and feelings of safety on the perceived restorativeness of the night-time environment.	Suburban pathway	Residents and pedestrians
2014	Paakkinen, M., Tetri, E. & Halonen, L. User evaluation of pedestrian way lighting	Light & Engineering	To evaluate user preferences for pedestrian lighting under different lighting conditions	Pedestrian way	Not reported
2014	Viliūnas, V., Vaitkevičius, H., Stanikūnas, R., Vitta, P., Bliumas, R., Auškalnytė, A., Tuzikas, A., Petrulis, A., Dabašinskas, L. & Žukauskas, A. Subjective evaluation of luminance distribution for intelligent outdoor lighting	Lighting Research and Technology	To establish the main subjective factors for the assessment of luminance distribution	University campus	Students
2015	Fotios, S., Unwin, J. & Farrall, S. Road lighting and pedestrian reassurance after dark: A review	Lighting Research and Technology	To investigate whether road lighting is associated with pedestrians' feelings of reassurance	Laboratory	Students and elderly
2015	Fotios, S., Uttley, J., Cheal, C. & Hara, N. Using eye-tracking to identify pedestrians' critical visual tasks. Part 1. Dual task approach	Lighting Research and Technology	To investigate the critical visual tasks of pedestrians	University campus	Not reported

2015	Fotios, S., Uttley, J. & Yang, B. Using eye-tracking to identify pedestrians' critical visual tasks. Part 2. Fixation on pedestrians	Lighting Research and Technology	To determine the importance of fixation on other pedestrians	University campus	Not reported
2015	Fotios, S., Yang, B. & Cheal, C. Effects of outdoor lighting on judgements of emotion and gaze direction	Lighting Research and Technology	To investigate the influence of road lighting on judgements of emotion and gaze direction	Laboratory	Students and university staff
2015	Juntunen, E., Tetri, E., Tapaninen, O., Yrjänä, S., Kondratyev, V., Sitomaniemi, A., Siirtola, H., Sarjanoja, E.M., Aikio, J. & Heikkinen, V. A smart LED luminaire for energy savings in pedestrian road lighting	Lighting Research and Technology	To evaluate the subjective lighting quality of an energy-efficient streetlight	Pedestrian road	Pedestrians
2015	Lin, Y. & Fotios, S. Investigating methods for measuring face recognition under lamps of different spectral power distribution	Lighting Research and Technology	To investigate the influence of SPD on facial recognition at different distances and durations	Urban streets	Students

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