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DOI: https://doi.org/10.1177/23998083241239383

Manuscript

Urban Analytics and City Science

EPB: Urban Analytics and City Science
2024, Vol. 0(0) 1–15

DOI: 10.1177/23998083241239383
journals.sagepub.com/home/epb
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The positive effect of blue luminescent pathways on urban park visitor's affective states: A virtual reality online study measuring facial expressions and self-reports

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Abstract

The colour blue often elicits feelings of calmness and contentment, for which evidence has largely been provided in daytime settings. It is unclear whether pathways illuminated in blue, for example, in urban recreational park areas at night confers the same positive impact on night time park visitors. To tackle this open empirical question, we investigated how adding blue self-luminous pavement to park lighting at night time affects park visitors' emotions compared to conventional white street light illumination. Our goal is to inform design decisions aimed at enhancing the emotional well-being of people outdoors at night in urban environments. Participants' emotional response was captured at four different time points while watching a video of a walk in a virtual urban park at night, which was lit with white street lights only or with the addition of blue luminescent pavement on the walked paths (between-subject design). To capture visitor's emotions, we used a simplified version of the Geneva Emotion Wheel (GEW) instrument and online facial expression recognition technology as subjective (self-reports) and objective (physiological) measures of emotion, respectively. The results of the GEW self-reports showed that the addition of a blue self-luminous pavement in a park during night time yielded more positive affect than standard white lighting in park visitors for the first half of the walk. In the second half of the walk through the park, participants' affective states seemed to equalize between the two lighting conditions. In contrast, sensory data on

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Data Availability Statement included at the end of the article

facial expressions indicated no difference between participants' emotional states over the whole walk in the two experimental conditions. Consistent with the positive emotional state perceived in the second half of the walk, the state of relaxation experienced after the walk also did not differ between the two lighting conditions. Furthermore, participants' relaxation judgements after the park walk were more negative overall for females than the more neutral ratings of males. Our results highlight the importance of lighting colour at night for the design of future affect-smart cities that may consider individual and group characteristics with the ultimate intent of promoting public well-being.

Keywords
Lighting colour, emotion, facial expression, virtual reality study, urban park

Introduction

Creating liveable and sustainable urban spaces that promote emotional well-being and positive affective states in their inhabitants is of primary concern in urban and environmental planning. Particularly in the context of modern smart cities, lighting during night-time hours plays a central role, not only in terms of functional interventions (e.g. energy savings), but also as a powerful visual emotional cue that can modulate the affective states of individuals and enhance their perception of safety (Scorpio et al., 2020). As already pointed out by Jacobs (1961), the city is not merely a physical space but is essentially a place of human encounters and interactions between individuals in an urban setting. With growing urbanization this interaction is increasingly confronted with the constant divergence between humans and their natural surroundings (Kaplan, 1992), which leads to an increase in people's mental fatigue, compromising their health and efficiency. Considering the mental, physical, and emotional health of citizens thus becomes very important to prevent diseases, as well as to promote well-being and healthy living (Grübner et al., 2017). To improve the living standards in cities, previous studies highlight how the addition of natural elements such as urban parks or the greening of house façades can reduce the divergence between people and their surroundings and increase people's well-being (e.g. Lin et al., 2014). At night, however, these green public places transform into dark sources of fear and insecurity (Nalla and Ceccato, 2020), primarily due to fear of crime (Franklin et al., 2008). As an effective strategy to mitigate safety concerns, Bogacka (2020) demonstrated that the implementation of well-lit walkways can enhance individuals' perceptions of safety. Notably, this effect is particularly pronounced among certain demographic groups, including women and older visitors (aged +50 years), who often report feeling less safe in urban parks compared to their male or younger counterparts (see Nalla and Ceccato, 2020). While adequate lighting can help make a place safer, it is unclear what lighting parameters are important to promote feelings of relaxation and positive emotions. Lighting consists of several parameters: colour, intensity, diffusion, and the position of the light source (Calvillo Cortés and Falcón Morales, 2016). Colour affects emotions such as fascination or alertness (Calvillo Cortés and Falcón Morales, 2016) that may lead to the perception of safety as well (Kaplan, 1992). Of all colours, blue and green have the most positive influence on human emotional states in terms of relaxation and well-being (Savavibool et al., 2016). Although both males and females consistently express a distinct preference for blue-green colours (Bonnardel et al., 2018), hue preferences may be influenced by subjective inclinations, past experiences, and geographical or cultural aspects as well (e.g. Al-Rasheed, 2015; Ou et al., 2012). Colour and lighting are useful tools for influencing emotions and well-being. However, thus far, research has focused on these factors independently, and mostly in daytime hours. There has been little attention on the combined role of colour and lighting in public spaces during nighttime hours. Design criteria for appropriate lighting conditions in public places would benefit from improved understanding of how to increase sense of safety and positive emotions. Indeed, how to improve outdoor areas intended for restorative purposes by making them more attractive is a question that is being asked more and more insistently also in northern European cities, especially during winter when daylight hours decrease dramatically (Costamagna et al., 2018).

Colour is also an important emotional visual cue to guide people through urban spaces (Jalil et al., 2012). Luminous-colour signage can be used as a warning sign for sensitive areas, such as crosswalks, intersections or dangerous roadsides, but also as a means of enhancing walkers' positive navigation experience and place-related emotional well-being. A salient example from recent policy developments in some European countries is the use of solar-powered photoluminescent paint-lit bicycle and pedestrian paths. The aim of this development is to increase safety at night, as well as cheaper and sustainable lighting, and reduced environmental or light pollution impact, compared with conventional lighting. These photoluminescent bicycle roads served as inspiration for our study into colour lighting in public spaces and their relationship with human emotions. In the next section, we discuss how human emotion is defined and measured, and how colour and lighting might influence the perception of urban spaces.

Background

How human emotions are defined and measured

Human emotions are feelings that an individual experiences in response to a specific object, event, or situation, and cause cognitive, physiological, and behavioural changes in our body and brain. They are typically described according to the three-dimensional scale of valence, arousal, and dominance (Scherer, 2005). Valence is defined as the degree of pleasantness of a given emotional stimulus and is typically measured with a continuous scale ranging from negative (e.g. sadness or fear) to positive (e.g. joy). Arousal, on the other hand, represents the intensity of the experienced emotion. It ranges from low intensity (e.g. calm) to high intensity (e.g. excited). Dominance is defined as the degree of control exerted by a stimulus, but is not an aspect of emotion that we focus on in the present study. One of the most widely used models for characterizing and measuring a specific emotion is the Russell's Circumplex model (Russell, 1980), which divides an emotion into the two dimensions of valence and arousal on orthogonal axes. The vertical axis of the model represents arousal, while valence is shown on the horizontal axis.

Accurately measuring human emotions remains a serious challenge because of their elusive, partly masked, and conflicting nature (Albert and Tullis, 2023). The most popular methods for capturing emotions are facial recognition, galvanic skin response (GSR), eye movement recordings, and self-reports with standardized test instruments (Albert and Tullis, 2023). Emotion measurement choice is related to the type of emotions one intends to capture. For example, facial expression metrics are particularly recommended for extracting only a few, targeted emotions such as joy (smiling) and surprise. Written self-reports are useful to measure a wide and diverse range of emotions (Albert and Tullis, 2023). A popular self-report instrument for measuring subjective emotional reactions to external stimuli is the Geneva Emotion Wheel (GEW; Scherer, 2005). It is designed to arrange the type and quality of an emotion in a two-dimensional circular space, while the intensity of the associated subjective feeling is indicated through distance from the circle's origin.

On colour theory and its associated emotions

We perceive an urban place through our sensory and emotional experience, for example, with its colours or light quality (Ryden, 1993). In architecture, colour is a decisive element in giving urban elements a certain character, such as creating harmony and unity, or contrasting and emphasizing (Bell, 1991). The colour of urban spaces can influence how people react emotionally to their surroundings, and thus can act as an emotional regulator and stress reducer. For instance, it can make a stressed person more relaxed or euphoric (Bell, 1991). However, choosing a suitable colour for lighting public places, acting as an emotional regulator, is not simple because of people's subjective preferences, experiences, and cultural backgrounds, as highlighted in the introduction section of this article. Although blue is used in the English and Japanese language to express sadness, such as 'feeling blue' (Takei and Imaizumi, 2022), previous studies in colour psychology suggested that this colour is often associated with positive emotions for most of the surveyed people (Palmer and Schloss, 2010; Valdez and Mehrabian, 1994; Wexner, 1954). In addition, a study evaluating the association of colour terms and colour patches with the emotions felt using the GEW questionnaire showed that whilst both the colours blue and white are related to relief, blue was also often associated with other positive emotions such as contentment (Jonauskaite et al., 2020). However, subjective colour inclinations may diverge depending on the object and the mental or symbolic association made between the object in question and a particular emotion (i.e. a cognitive emotional response). While one might have a positive association between the blue colour of lighting with that of the sky or water (Palmer and Schloss, 2010), one might also associate it with blinking emergency signals on buildings or vehicles, or even with blue-coloured fires glowing on graves or moors, thus evoking negative past experiences or negative emotional states (Jacobs and Jacobs, 1958).

Although there are already several empirical studies on the effect of lighting colours on human emotions (e.g. Masullo et al., 2022), these have mostly been related to interior lighting and with inconsistent outcomes regarding emotional responses. For example, in a recent study using 2D static representations of architectural spaces, participants reported higher positive valence ratings for indoor environments illuminated with cold colours (e.g. green and blue) compared to warm (i.e. red) colours (Wilms and Oberfeld, 2018). In contrast, Küller et al. (2009) found that a blue illuminated office space is experienced as less pleasant than a red-lit office space. Colour hue may also yield contradicting effects on arousal. For example, warm colours of an indoor living room tended to produce stronger participant responses when rating adjective terms such as 'high arousal', 'exciting' and 'stimulating'. Conversely, while cool colours tended be associated with 'not very arousing' in that study, they were also rated higher on the adjectives 'spacious' and 'restful'. In contrast, Kuijsters et al. (2015) found that an indoor space illuminated with cool (i.e. cyan) accent colours can increase physiological arousal compared to an indoor space illuminated with warm (i.e. orange) accent lighting.

At the current state of the present study, empirical evidence on the physiological effects of coloured lighting on human emotions is inconsistent. We still lack empirical evidence for generalizable colour principles related to emotional effects to inform outdoor design decisions, and thus individual use cases might be therefore useful to study empirically. In particular, there have been a few practical showcases on the impact of self-luminous pavement colours on emotions, such as Roosegaarde's project for interactive and sustainable roads (https://studioroosegaarde.net/project/smart-highway), which also aligns with 2030 Sustainable Development Goals (https://sdgs.un.org/2030agenda).

The present study

To fill above mentioned empirical gap, we thus set out to empirically evaluate the effect of lighting colour outdoors, that is, standard white street lights with the addition of blue luminescent lit pavements (between-subject design) on the emotions experienced by people watching a video of a virtual walk in an urban park at night. For our online study, we administered the GEW and included physiological responses (i.e. facial expressions) to capture and interpret participants' emotional states, as recommended in affective psychology (Batistatou et al., 2022). We asked participants to watch several videos that depicted a stroll through an urban park at night-time online, in a first-person view, instead of bringing them to our virtual reality lab. This, because of the ongoing global health pandemic. These videos were created with state-of-the-art virtual reality technology. Following the park experience, participants were asked to fill in questionnaires responding to their experiences and feelings. Our work was led by the following research questions:

- **RQ1:** How does the lighting colour of an urban park at night affect visitor's emotions?

Based on research in the field of colour theory, we hypothesize that the addition of a blue luminescent pavement on the walked park pathways would promote the feeling of positive emotions (relaxation or happiness) in study participants more than white street lighting only; this should be reflected in both participants' self-assessment and through their facial expressions.

We further include the variables gender and light exposure duration to gain further insights on those factors that may also influence park visitors' emotions, and thus ask:

- **RQ2:** How does the effect of lighting colour on emotion vary as a function of gender and exposure time to the lighting condition?

Methods

Participants

Forty-eight healthy adults were recruited via Prolific (https://www.prolific.co) in exchange for monetary compensation. The age distribution across conditions (randomly assigned) were as follows: white condition: 73.9% 20–30 years, 17.4% 31–40 years, and 8.7% < 20 years old; blue condition: 68.0% 20–30 years, 16.0% 31–40 years, and 8.0% < 20 years old. Although the number of recruited females largely exceeded the number of males, the gender of the participants in each group was balanced (white condition: 15 females; blue condition: 15 females). All participants gave informed consent before participating in the study, and the study was approved by the Ethics Committee of the institute.

Experimental design

This study followed a 2 × 2 × 5 mixed design, with the between subjects IVs of lighting (white street lights vs blue self-luminous pathway) and gender (male vs female), and the within subjects IV of time point (baseline, 1, 2, 3, 4). For the remainder of this paper, we will refer to the experiment scenario containing the blue self-luminous park pathways as the *blue condition* and for the scenario with the conventional white street lights as the *white condition*. Participants were randomly assigned to either the white or to the blue conditions. The video test stimuli were presented to all participants in the same sequence. First, all participants watched a video of a roller coaster ride, serving as a baseline emotion recording before watching a video of a night stroll through a virtual urban park in four segments. The segments were interleaved with an adapted version of the Geneva Emotion Wheel (GEW) questionnaire to assess participants' subjective emotional arousal and subjective emotional valence. After the experiment, a relaxation-related question was presented to participants to measure their relaxation state. We also measured relaxation levels following the entire walk using a post-test questionnaire because relaxation was the emotional state we expected to achieve after the walk in the park, especially under the blue condition. Furthermore, we asked participants to provide justifications for their assessments to obtain further insights into their feelings and their affective state induced by the blue self-luminous pavement on the walked pathway. Throughout the experiment, we also recorded the facial expressions and eye movements (not analysed in this paper) of the participants, as described in more detail in Section 'Materials'. The flowchart shown in Figure S1 provides a more detailed overview of the experimental design and procedure.

Task and procedure

Sitting in front of their laptop or desktop computers, participants read the information sheet about the experiment and provided their informed consent online. Subsequently, they were asked to check their sitting position and lighting condition, that is, sitting upright at a desk with the appropriate distance from the screen and with enough light on their face. After performing the eye movement calibration process online, they were instructed on the GEW questionnaire. Successively, they were asked to watch a two-minute video sequence showing a roller coaster ride. We chose this video to induce the same positive feeling of excitement in all participants as a baseline before the park walk. This video was retrieved from an empirically standardized public interactive 360° video database of emotion at Stanford University (see Figure S9; https://www.stanfordvr.com/360-video-database; Li et al., 2017), which was then converted to a regular non-interactive video with a first-person viewing perspective. The video has a corresponding reference valence rating of 6.17 and an arousal rating of 7.17, on a 9-point scale of the self-assessment manikin (SAM; Lang, 1980), meaning that the roller coaster ride is able to induce joy and excitement in viewers. At the end of this video sequence, a GEW questionnaire automatically appeared on participants' screen, where they were asked to judge their affective state at that moment, and which we considered as self-declared baseline affective state. After responding to the GEW, participants were given instructions regarding the study task and asked to read an introductory scenario. They were asked to imagine the following situation: '*You are visiting a city you have never been before. It is slowly getting dark outside. As the day has already been rather exciting you would like to relax a bit before getting back to the hotel. One of the locals tells you about a nice neighbourhood park, just a few blocks down the road from your hotel. You decide to visit this place at the end of the day. You will be virtually walking through this park. You do NOT need to move on your own. Just enjoy your walk. The walk will have four stops with different views where we will ask you how you feel, using the response wheel you have seen earlier*'. Next, they saw the four video sequences of the park stroll, interleaved with their GEW responses. The self-reported valence and arousal ratings collected with the GEW will hereafter be referred to as subjective valence and subjective arousal measures. After the main experiment, participants completed a post-test questionnaire, in which we collected their overall experience of their virtual park stroll including self-reports on their felt degree of relaxation, as well as demographic information. The entire experiment lasted approximately 25 min on average.

Materials

Apparatus. To collect participants' facial expression data and emotion self-reports, we used the iMotions 9.3 online data collection (ODC) tool (https://imotions.com). As the entire study was conducted as a full-online experiment because of the COVID-19 global health pandemic, participants used their own desktop or laptop computer to access the online study. The only technical requirement to participate in the experiment was a computer equipped with a webcam and a fast Internet connection. The test videos were streamed instantly during the experiment, while participants' facial expression data were captured thought their webcam in real-time and then uploaded from the client to the iMotions cloud once the experiment was completed. We also collected participants' eye movements through their webcam leveraging eye tracking technology integrated into the iMotions ODC solution. Eye-tracking data can be combined with facial expression data using the iMotions tool to further identify where and when in the park a participant had a certain emotional response during the walk, and which specific visual stimulus or park feature induced this response. Eye movement behaviour is not the focus of the present study and so we do not provide any further details on this data.

Virtual environment. The virtual environment was created from scratch using Unreal Engine 4 (https://www.unrealengine.com). Two different lighting scenarios were developed for the two experimental conditions: one environment illuminated with white street lights (RGB = 255, 255, 255) and a blue self-luminous pathway (RGB = 0, 0, 255) and the other with white street lights (RGB = 255, 255, 255; see Figure S2) only. The blue self-luminous park pathway in our study has been inspired by the blue fluorescent paint used to illuminate a bicycle lane near Lidzbark Warmiński in Poland, which contains phosphors that are charged with sunlight during the day and then glow during the night (see Figure S8; https://warszawa.wyborcza.pl/warszawa/51,34862,20752021.html#S.galeria-K.C-B.1-L.1.duzy). Our park has an area of about 40,000 m^2, and the entire route shown in the videos was approx. 1 km long (Figure S3). The park was created within a larger urban space that served as a background, with several illuminated buildings visible around the park's edges to give participants the feeling of being in a realistic urban environment. The park route was divided into four different path segments, shown in four separate video sequences. Each path segment ended with a *checkpoint* (CP1–CP4 in Figure S3, and Figures S10-S17), depicted with a given park feature (i.e. a flowerbed, a city viewpoint, a fountain and a statue), after which the GEW questionnaire appeared. The four selected park features, identical in each experimental condition and thus experienced by both experimental participant groups, are commonly found in parks and have shown to induce calming effects, as evidenced by past studies (e.g. Peschardt and Stigsdotter, 2013). The first three video sequences were 1 minute in duration each, while the last video lasted 1 minute and 40 seconds. Each video visualized the park from a first-person viewing perspective at an average walking speed of 12 km/h. This speed, corresponding to running in the real world, was determined after a pilot test conducted with a couple of participants. Using this walking speed, aiming to make the park walking experience in VR both realistic and enjoyable, was also justified by the design literature for video gaming design and for VR studies, which highlights how people tend to underestimate their walking speed in a VR setting, meaning that they perceive it as much slower than it would be in reality (e.g. Plumert et al., 2005).

Objective measures and self-evaluation of affective states. As suggested by Albert and Tullis (2023), we combined automated facial expression capturing technologies with self-reports to measure participants' emotional states elicited by the five video sequences. By combining physiological with self-report emotion measurement methods, we thus expected to obtain a reliable picture of participants' emotional states. To measure participants' emotions in real-time, we used Affectiva's AFFDEX technology (https://www.affectiva.com) integrated into the iMotions software, see the Methods section of the Supplementary Materials for more information. As mentioned earlier, we collected self-declared affective states using a simplified version of the GEW (Scherer, 2005) questionnaire considering both the valence and arousal of participants' virtual park experience after strolling through each park path video segment. The original GEW contains at least 20 different emotions (Scherer et al., 2013). As we found most of these emotions not pertinent to our study, we thus reduced the questionnaire to only four emotions, that is, *alarmed, happy, relaxed, and sad*, one representative for each quadrant of the Russell's two-dimensional valence-arousal space (Russell, 1980; see Figure S4).

Three of these four selected emotions are also captured by the selected Affectiva online facial expression recording tool, that is, *alarmed, happy, and sad,* and thus can be compared directly between the two emotion assessment methods used. The intensity of an emotion was measured by averaging the arousal ratings, which ranged between 1 (low intensity) and 5 (high intensity), assigned to the four emotion categories in the GEW. To be consistent with the dark colour scheme throughout the experiment, the implemented GEW was designed in white and light grey on a black background. The purpose of this *dark mode* was consistency in display salience and thus to not alter participants feelings or emotions.

Self-evaluation of relaxation state. After completion of the urban park tour, we asked participants to judge how relaxing the experience park environment was on a 5-point Likert rating scale, ranging from 1 'not relaxing at all' to 5 'very relaxing', and with a 'neutral' category in the middle.

Results

Effect of park lighting colour, time point and gender on park visitors' self-reported emotions

Subjective valence. First, we examined the dependent variable of subjective valence. We grouped participants' self-reported emotions according to positive (happiness, relaxation, and no emotion) and negative emotions (sadness and alarm). We included neutral responses in the positive group because there were too few data points for a dedicated category as we would have preferred, but since our research question pertained to alleviating the negative emotions usually associated with public spaces at nighttime, we interpreted the very few neutral emotion responses as a positive outcome (i.e. not negative). A binomial logistic regression (see Table S1) was performed with lighting colour (i.e. white and blue; sum contrast coding), gender (male, female; sum contrast coding), and time point (baseline, 1, 2, 3, 4; successive differences contrast coding) as predictor variables and the GEW responses as the outcome variable (positive or negative emotions).

Overall, we found a significant effect of colour lighting on participants' subjective valence ($B = -0.75$, $p < .001$) showing that participants were more likely to feel positive emotions if exposed to blue compared to white lighting. Moreover, we found a significant change in participants' valence after viewing the first path video compared to the baseline video ($B = -1.57$, $p = .003$) such that participants were more likely to experience negative rather than positive emotions. There was no significant effect of gender nor any significant interactions (see Table S1 for full valence model results).

In order to more precisely examine the distribution of responses over emotion categories we used Fisher's exact test (FET) to determine if there was a significant association between participant's specific emotions (alarmed, happy, sad, no emotion, relaxed) and lighting colour (white, blue) for each of the park path video segments (Figure S6). There was no difference in the distribution of emotions between conditions for the baseline video ($p = .077$). The distributions of responses across emotional categories were significantly different between conditions for path video 1 ($p = .004$) and path video 2 ($p = .021$). The distribution of emotional responses in each lighting condition reached equilibrium in the latter half of the park stroll, with no significant differences in response distribution for the categories in videos 3 ($p = .166$) and 4 ($p = .735$). To study potential differences in the distribution of emotions between lighting conditions between videos 1 and 2, we performed pairwise FET for each emotion and time point (10 tests in total) to identify specific emotional shifts driving an effect. For some emotions there were insufficient counts to perform statistics, and for all other emotions there were no significant effects of lighting (ps >= .182).

Subjective arousal. Next, we examined the dependent variable of subjective arousal. A multiple regression (see Table S2) was performed with lighting colour (i.e. white and blue; sum contrast coding), gender (male, female; sum contrast coding), and time point (baseline, 1, 2, 3, 4; successive differences contrast coding) as predictor variables and the GEW responses as the outcome variable (numeric; 1–5). There was a significant effect of gender (B = 0.19, p = .034) showing that males rated overall arousal higher than females, and there was a significant interaction between gender with the video segments 2 versus 3 contrast (B = 0.62, p = .028). This interaction can be explained by a sharp rise in arousal over these path segments for males, whilst the arousal levels of females dropped. Interestingly, there was a significant change in arousal between path videos 1 and 2 (B = −0.68, p = .016) showing an overall drop in arousal, that did not interact with gender (B = −0.12, p = .655). There were no other significant effects nor significant interactions (see Table S2 for full model results).

Subjective relaxation ratings. We assessed whether gender influenced how participants judged their relaxation state after completing the virtual stroll through the urban park. We conducted a multiple regression with colour lighting (i.e. white and blue; sum contrast coding) and gender (male, female; sum contrast coding) as predictor variables and relaxation ratings as the outcome variable (numeric, 1–5). As predicted, males reported significantly higher post walk relaxation than females (B = 0.44, *95% CI* [0.10 – 0.79], p = .012; see Figure S7). Contrary to our expectation, there was no significant effect of condition (B = −0.24, *95% CI* [−0.58 – 0.10], p = .166), and no significant interaction between gender and condition (B = −0.07, *95% CI* [−0.42 – 0.27], p = .670).

Effect of park lighting colour, time point, and gender on park visitors' facial expressions

Facial expression derived valence and engagement. Participants' facial expression derived valence and engagement mean scores are reported in Table S3. We conducted two multiple regression models with lighting colour (i.e. white and blue; sum contrast coding), gender (male, female; sum contrast coding), and time point (baseline, 1, 2, 3, 4; successive differences contrast coding) as predictor variables, and valence and engagement as the respective outcome variables (shown in Tables S4 and S5, respectively).

For valence, in line with the GEW analysis, we found a significant effect of lighting condition (B = −2.61, *95% CI* [−4.55 to −0.68], p = .008) such that blue self-luminous pathways yielded more positive valence, and significantly more negative valence in path video 1 compared to the baseline video (B = −6.34, *95% CI* [−12.63 to −0.04], p = .049). In contrast to the GEW analysis, there was also a significant effect of gender (B = −5.57, *95% CI* [−7.56 to −3.59], p < .001). There were no significant interactions (see Table S4 for model results). For engagement, there were no significant effects of gender, condition or time, and no significant interactions (see Table S5 for model results).

Discussion

We investigated whether nighttime path lighting colour in a virtual urban park had an impact on human's emotions, particularly on the affective state experienced during, and the feeling of relaxation after completing, a virtual stroll through this park. As hypothesized, our results showed that the blue luminescent pathway elicited a more positive feeling than standard white lighting only, according to both participants' self-reported and objectively measured emotional valence. This is in line with previous studies on colour theory, which stated that blue is often associated with positive and low-aroused emotions, such as calmness and comfort (Clarke and Costall, 2008; Hanada, 2018; Jonauskaite et al., 2020; Schaie, 2010; Wexner, 1954).

We found that our participants' emotional state was subject to change over time and across lighting conditions. After the first segment of the virtual urban park stroll, participants experienced more negative than positive emotions. After watching the second park video segment, however, the evolution of emotional state diminished. The effect of the lighting colour was also found during the first half of the park stroll, and then faded in the second half. After the first and the second park video segments, participants reported feeling emotions with more negative valence in the white condition compared to the blue condition. The blue colour of the pavement seemed to attenuate this initial shift to negative emotions. In fact, participants in the blue condition rated their emotional state as less alarmed and happier than the white lighting group in these two initial segments of the park stroll. However, the discrepancy between negative and positive emotions, in which the negative ones prevail in the white illumination group, seems to gradually become more balanced as time passed. After the third and fourth park video segments, we no longer found significant differences in participants' subjective valence between the two experimental conditions. This result can be explained by the iterative reprocessing model of affect (Cunningham et al., 2013), which pointed out how people's affective state changes iteratively over time with the perception and continuous processing of new information acquired in the environment. Initial responses to emotionally laden cues are usually automatic and unreflective, but through subsequent cognitive processes they are updated and nuanced resulting into more stable and long-lasting affective states (Oya et al., 2002). Similarly, when participants enter an unfamiliar virtual park in the dark for the first time, as in our study, it may initially put them into an affective state with heightened levels of arousal, possibly with a behaviour that may be characterized by non-reflective motivational avoidance, as suggested by Oya et al. (2002). This contrasts with their previous exciting experience of the roller coaster ride. While riding a roller coaster themselves might not be novel to many participants, many might still have seen this in movies or observed others riding it, etc.

As with participants' perceived valence, self-reported arousal seems to be influenced by the moment after the park video segment when they judged their emotions, although the significant reduction in emotional arousal occurred later than the valence reversal. For the baseline video and the first segment of the park video, the two dominant emotions were happiness first and alarm later, both of which were experienced with high arousal, and then decreased in the later segments of the park video, where a balance between negative and positive emotional states emerged. Russell's circumplex model of affect (Russell, 1980) refers to alarm and happiness as emotions of medium to high intensity. The distribution of the means in Figure S6 suggests that the dampening of the emotional state might be explained by the increase in relaxed and happy states, and a reduction in alarm. However, although the regression models and FET indicate a shift in emotions, from positive to negative and between specific categories, post hoc tests within time points for each emotion do not identify the specific emotions driving the overall effect. We believe the failure to identify the specific shifts in emotions is likely because breaking the data down to such a fine level (1 time point, 1 emotion) greatly reduced our statistical power. Therefore, whilst our data shows that a shift in emotions does indeed occur in response to virtually experiencing a public space, further research is required to concretely identify the driving emotions of this effect.

Next, we investigated whether and how lighting colour affected participants' overall relaxation experience after the virtual stroll in the park. In contrast to our hypothesis, no significant differences were found between the relaxation scores of the two lighting conditions. From the results obtained, we can see that the beneficial effect of the blue illumination colour on participants' affective states is found only during the first half of the park stroll, then, in the second half and after completing the stroll, the participants' emotional state became more neutral and equalled that of the white lighting. However, the perception of relaxation after walking the entire route was found to differ by gender. This is in line with previous studies (e.g. Koskela and Pain, 2000; Sreetheran and van Den Bosch, 2014; Valentine, 1990) which highlighted how women (and the elderly) typically tend to have higher levels of fear in dark urban green spaces compared to men (and younger people). Only 17% of females reported experiencing a medium to high level of relaxation (i.e. somewhat to very relaxed), compared with males, whose medium to high level of relaxation was 56%.

During the route, our analysis showed a drop in arousal for all subjects by the middle of the route, after which the male subjects showed a sharp increase that persisted for the rest of the experiment, whereas female arousal ratings continued to decline to the post experiment ratings. Interestingly, the valence rating analysis showed no significant differences across gender groups, thus female and males reported equal frequencies of positive emotional states. Taken together, the valence analysis results show that males and females experienced a similar increase in positive emotions in their response to the blue luminescent pathway, but the intensity and strength of those positive feelings were greater for males, according to the arousal analysis. The fact that males experienced more intense positive emotions could explain why their post-test relaxation ratings were higher than for the females, thus showing a stronger persistence of positive affect compared to females. Females instead showed a significant drop off in relaxation in their self-reported post-test responses which may be due to their low arousal, thus less strong emotion response associated with their positive emotional state during the walk. Hence, our findings indicate that the impact of environmental lighting and colour is not only related to moment-to-moment fluctuations in emotional state but also builds a lasting impact on individuals even when they are no longer exposed to that stimulus, which is also dependent on the strength of their initial response. How long this persists has yet to be answered but the importance of environmental influence on emotional state is clear.

Considering the divergence between males and females, colour and lighting should be adapted to the target population. Although the lighting effect did not interact with gender (i.e. it worked equally well for both groups in promoting positive emotions), our results showed that females may be more prone to a post-experience shift towards a negative emotional state in response to the nighttime environment. An experimental aspect should also be emphasized: similar empirical studies should include and contrast female and male samples. It is also possible to focus more on women as a target group, who are more influenced by the emotional aspect of the environment. Our outcomes highlight how, especially women, need more investigation on how to improve their emotional well-being and make them feel safer in public spaces at night because this is the time when people are most vulnerable in case of aggression (Badiora et al., 2020; Jorgensen et al., 2013). The challenge shown by our results is that the female population may be more prone to adverse emotional responses, but also more resistant to the effects of possible interventions designed to alleviate them, as is shown by reduced arousal of positive valence, and by our post-test ratings. Therefore, it is important to represent this group when testing possible interventions that may appear more effective when tested on different samples, such as males in our study.

Finally, results of the facial expression analyses were mixed. On the one hand, the analysis of expression derived valance replicated the lighting condition and path segment effects we observed with the GEW. On the other hand, there was disagreement on the role of gender in emotional valance during the park stroll. Further, our analysis of expression derived engagement found no significant effects of lighting, path segment or gender, in contrast with the results of the GEW arousal data, which suggested that intensity of emotions varied with gender and path segment.

Given the low number of facial expressions detected by the software – most of the facial expressions captured during the experiment were classified as neutral expressions – it is possible that facial recognition technology is most reliable in the presence of strong sensory stimuli, such as movies with high emotional content, for example, violence, love or very surprising scenes (Albert and Tullis, 2023), and, as we also found, when measuring valence during the excitement provoking baseline video, which was as expected higher and more positive than during the park videos. Considering that Affectiva technology currently is the world's largest database of spontaneously generated facial expressions (Albert and Tullis, 2023), and largely validated in the last few years (Guan et al., 2021), one possible explanation for this may be traced to the fact that participants' emotional responses captured through facial expressions induced by our urban park video stimuli were not strong enough to evoke any of the seven core emotions that could be detected by the used software or categorised by the software with high confidence. The probability that the categorized expressions correspond to any of the seven core facial emotion expressions was very low (10.90%). Given the low confidence of the emotion classifier, we would caution future studies against relying solely on facial recognition measures when studying human emotional responses. Another possibility could be that the neutral faces captured by the software reflect a calm feeling, as found by Wei et al. (2020) for an urban park setting. Possibly the combination of additional biometrics, such as electrodermal activity (EDA) measures or electroencephalography (EEG), coupled with eye tracking could help develop facial expression analysis to capture weak emotional responses or more complex affective states.

The choice of a between-subjects design offered some advantages to our study, but this comes in hindsight also with limitations. The main advantage lay in the ability to present participants with only one level of the independent variable, thus safeguarding their behaviour from the influence of the alternative level, especially tricky with emotional responses that build slowly, and also minimizing the potential for participant fatigue or boredom (Martin, 2000). However, this design choice introduced some drawbacks, namely, increased susceptibility to individual variation, and potential impacts of hard to control environmental factors, especially important for the online setting as these are hard to control. To address these limitations, future research might consider adopting a within-subjects design, which may help mitigate the aforementioned challenges and also increase statistical power. Along those lines, the use of different park settings with different or additional park features per segment could improve our ability to capture even the most subtle nuances of individual emotional states during the park walk.

Additional research directions that we find interesting are to: (1) replicate our study in the laboratory using other biosensors such as EDA to obtain a more reliable picture of participants' emotional states, and in ecologically valid real-world urban park settings, (2) further investigate how females, as a target group, perceive emotions and safety in colourfully illuminated public spaces at night, and (3) test the impact of other lighting parameters such as light intensity and additional colour hues on people's emotional well-being in urban parks. One possibility could be to explore the emotive potential of specific colours, such as warm hues (i.e. red, orange and yellow) and cold hues (i.e. green, cyan and magenta), as their emotional impact may vary by context. For instance, red may elicit positive emotions when associated with love, while concurrently invoking negative emotions when linked to wounds or war (Jonauskaite et al., 2020).

Conclusion and outlook

This study investigated how the use of blue luminescent lighting on pathways, in addition to standard white street lighting, in an urban park at nighttime influences the emotional experience of individuals. The salient findings of this study are: (1) the use of a blue self-luminous pavement in an urban park at night was more effective at increasing emotional well-being than conventional white street lights alone, (2) relaxation after the stroll was not promoted by the blue colour of the pavement, and (3) females experienced less relaxation than males. This study also provides new methodological insights and highlights the limitations of current online technologies aimed at capturing human emotions during studies with online users.

Author's note

This research was carried out at the Department of Geography at the University of Zurich as part of the Master's thesis research by the second author, supervised by the co-authors, Sara Lanini-Maggi and Sara Irina Fabrikant.

Acknowledgements

We thank the reviewers for their constructive and helpful feedback. Without the willingness of our participants to be part of this empirical study during lockdown times in a global health pandemic, there would have been nothing to report at all. We thank them for taking the time and effort! We are indebted to the generous funding by the European Research Council (ERC) Advanced Grant GeoViSense, no. 740426.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by the European Research Council (ERC) Advanced Grant GeoViSense [#740426] and the Digital Society Initiative of the University of Zurich.

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Data availability statement

The statistical data and R-code are available at the following URL: https://gitlab.uzh.ch/giva/geovisense/lightingcolourstudy.

Supplemental Material

Supplemental material for this article is available online.

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