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How Much Lighting is Required to Feel Safe When Walking Through the Streets at Night?

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Abstract: Public space lighting (PSL) is indispensable after the natural dark. However, little is known about how much PSL people actually need to feel sufficiently safe in different real-world urban settings. The present study attempts to answer this question by employing a novel real-time interactive approach, according to which, observers use a specially-designed mobile phone application to assess and report the perceived attributes of street lighting and the feeling of safety (FoS) it generates. To validate the proposed approach, a systematic survey was conducted in three cities in Israel—Tel Aviv-Yafo and Haifa, which lie on the Mediterranean coast, and Be’er Sheba, which lies inland. Additionally, instrumental PSL measurements were performed at the same locations. As the study reveals, the necessary level of illumination required by urban residents to feel safe differs by city and is significantly higher in Be’er Sheba, other factors held equal, in compare to Haifa and Tel Aviv-Yafo. This difference may be attributed to stronger daylight that the residents of the desert city of Be’er Sheba are accustomed to, and, therefore, may prefer stronger nighttime illumination. The difference could also be related to the relatively low socio-economic status and somewhat higher crime rates in the latter city. Findings also show a significant and positive association between FoS and instrumentally measured PSL levels, although this association exhibits diminishing returns. To the best of our knowledge, the present study is the first to use an interactive location- and time-based mobile phone technology, which can potentially provide more accurate and reliable assessments, compared to traditional “pen and paper” survey techniques.

Keywords: Feeling of Safety (FoS); Public Space Lighting (PSL); interactive user-oriented approach; urban areas

1. Introduction

Public space lighting (PSL), if adequately designed, promotes the feeling of safety (FoS), increases comfort, defines spaces, and forms neighborhood identities [1]. However, if excessive or misdirected, PSL leads to energy waste, increases greenhouse gas emissions [2,3], and poses non-negligible threats to human health [4–7] and natural ecosystems [8–10]. The relation between urban residents and their physical environment is a major field of study in environmental psychology [11,12]. According to the Theory of Place (ToP), residential satisfaction results from gratification associated with living in a specific place [11], and involves cognitive, affectional and behavioral components [13–17]. An important component of this gratification is *feeling safe outdoors*. Studies have shown that the percent of people who feel safe drops significantly after dark, as fear increases when visibility is impaired, and fewer people are around [18,19]. This fear often stems from the fact that reduced visibility provides offenders with more opportunities for concealment and makes it harder to identify escape routes [20].

The essential contribution of artificial lighting to FoS in urban areas has been emphasized in several studies [21–28]. In particular, studies have shown that PSL may affect FoS by improving

visibility and reducing concealment. As Peña-García et al. [25] conclude, well-illuminated streets, where lighting is uniform and illuminance levels are high, make people feel comfortable and safe.

Although it is well established that people's concerns for personal safety increase at night, and good street lighting is a way of improving FoS [18,19,25,29], the relation between FoS and PSL needs further investigation. The main limitation of most previous studies is that they were carried out in *controlled or laboratory conditions*, thus, being unable to account for complex environmental conditions, such as the presence of traffic and other pedestrians, weather and vegetation [20,30–32]. Furthermore, most previous studies of FoS-PSL association involved a relatively small number of research subjects and evaluated a relatively small number of illumination sources, thus, falling short of representing diverse *real-world* urban settings, multiple lighting sources, larger populations and population subgroups [1,33].

This study attempts to address the above-mentioned drawbacks and, specifically, answer the following two main questions:

- (a) What levels of public space illumination do people actually need to feel sufficiently safe at nighttime in an urban environment?
- (b) Do these minimal illumination levels differ across different urban settings?

2. Materials and Method

The study employs an interactive, user-oriented, approach, according to which observers assess *in-situ* various PSL attributes and report their FoS using a specially-designed mobile phone application. In parallel, the same PSL attributes are instrumentally measured at the same sites. Next, the association between the reported FoS assessments and the measured lighting attributes is examined and modelled using multivariate statistical tools. These study phases are presented in Figure 1 and elaborated in the following subsections.

Figure 1. Study layout.

2.1. Selection of Survey Sites

The study was carried out in three cities in Israel—*Tel Aviv-Yafo*, *Haifa* and *Be'er Sheba*—which differ by population size, climatic conditions and socio-economic status (SES), but are similar in building typology and development patterns (Table 1). Tel Aviv-Yafo with about 450,000 residents, is the second largest city in Israel (after Jerusalem), followed by Haifa (285,000 residents) and Be'er Sheba (210,000 residents). Both Tel Aviv-Yafo and Haifa are onshore cities, located along the Mediterranean coast, which receives around 580–680 mm of annual rainfall. Concurrently, Be'er Sheba is an arid city, located inland and characterized by rainfall scarcity, rarely clouded sky and sparse vegetation (Table 1).

Table 1. Physical, environmental and socio-demographic characteristics of the cities under study (as of 2018, unless stated otherwise) ^a.

Development Attribute	City		
	Tel Aviv-Yafo	Haifa	Be'er Sheba
Population size (thousands)	447.70	282.40	208.30
Area (km ²)	52.00	63.67	117.50
Population density (per km ²)	8354.70	4045.50	1733.20
Climatic zone	Mediterranean	Mediterranean	Hot semi-arid with Mediterranean influences
Socio-economic status (SES) ^b	8	7	5
Average precipitation (mm)	583.0	683.0	195.1
Average precipitation (days)	71.00	65.00	39.20
Average relative humidity (%)	67.00	69.00	42.00
Ethnic makeup (%)			
• Jews	91.80	82.00	88.00
• Arabs and others	8.20	18.00	11.00
Place of birth (% for Jews)			
• Israel	69.00	52.00	55.0
• Asia	3.00	1.00	2.00
• Africa	16.00	22.00	22.0
• Europe and America	2.00	4.00	8.00
Crime rates (per 1000) as of 2016, including: ^a	3.60	3.05	4.76
• Bodily harm	0.62	0.63	0.86
• Sexual offences	0.05	0.05	0.07
• Property offences	0.67	0.70	0.74

^a Assembled or calculated using data from Reference [34]. ^b Social-economic rating of Israel local authorities: from 1 (the lowest) to 10 (the highest).

At each city, survey sites were selected using a 2 × 2 factorial design, to cover four most typical cases of outdoor illumination:

- High illumination level with a predominant short wavelength (“blue”) light spectrum;
- Low illumination level with a predominant short wavelength (“blue”) light spectrum;
- High illumination level with a predominant long wavelength (“red”) light spectrum, and
- Low illumination level with a predominant long wavelength (“red”) light spectrum.

Outdoor lighting with predominant emissions in the short wavelength (“blue”) part of the light spectrum may bring economic benefits, as it minimizes energy waste, while preserving visual performance in places where low-illuminance levels are needed [35]. Nevertheless, empirical evidence about the adverse impacts of such lighting on circadian rhythm and melatonin secretion in wildlife and humans cannot be ignored [36,37]. Concurrently, health and ecological impacts of exposure to the *long wavelength* (red) part of the light spectrum appear to be less severe [38,39].

In each city, site selection for the field survey was carried out using the latest satellite images, taken from the International Space Station by a Cannon still camera with a 200/400-mm focal length. This camera separately records light emissions in the red, green and blue (RGB) bands by using different color filters [40].

To ensure the applicability of the study results for future practices, we added several additional criteria for survey sites selection: urban area type, building typology, buildings' age, SES, and main land use. First, we selected predominantly residential areas with multi-story buildings constructed in the past two decades, which represent typical examples of present-day urban housing typology in Israel. Next, we selected neighborhoods with as similar as possible SES, based on the latest available information (see Appendix A). We also excluded residential sites with large-scale, and/or heavily lit, commercial land uses, which may attract multiple visitors and consequently alter personal FoS. The screening process yielded 10 neighborhoods: *Four* neighborhoods in Tel Aviv-Yafo, *three* in Haifa, and *three* in Be'er Sheba. Appendix A reports basic development indicators and light characteristics of each neighborhood, while Figures 2–4 present street maps of the neighborhoods and their geographic location in the cities' boundaries. Additionally, Figure 5 illustrates the neighborhoods' lighting environment during nighttime.

(a)

Figure 2. *Cont.*

Figure 2. Location of the survey neighborhoods and survey routes in Tel Aviv-Yafo: (a) Neighborhoods surveyed; (b) “Nahalat Yitshak” (NY); (c) “HaTsafon HaHadash” (C); (d) “Neve Avivim” (NA); (e) “Ramat Aviv Ha-Hadasha” (RAH).

Figure 3. Location of the survey neighborhoods and survey routes in Haifa: (a) Neighborhoods surveyed; (b) “Neot Peres” (NP); (c) “Ramat Ben Gurion” (RBG); (d) “Yizra’eliya” (Y).

Figure 4. Location of the survey neighborhoods and survey routes in Be'er Sheba: (a) Neighborhoods surveyed; (b) "Never Ze'ev" (NZ); (c) "Yud-Alef" (YA); (d) "Tet" (T).

Figure 5. Cont.

Figure 5. Nighttime lighting environment in selected neighborhoods under study. (a)—Neighborhood “Tet”, Be’er Sheba; (b)—neighborhood “Neot Peres”, Haifa; (c)—neighborhood “HaTsafon HaHadash Center”, Tel Aviv-Yafo; (d)—neighborhood “Ramat Aviv Ha-Hadasha”, Tel Aviv-Yafo.

2.2. Selection of Survey Routes

In each neighborhood, a pedestrian route, stretching for about 800–1000 m, was designed to cover main and secondary streets, as well as open spaces, such as children playgrounds and parks (if present). Along the sidewalks of each route, about 20–30 survey points were selected at intervals of 20–30 m from each other (see Figures 2–4). Altogether, 257 reporting points were selected in 10 neighborhoods. To represent typical PSL along each route, survey points were located at least 10 m away from “atypical” local light sources, such as spotlights or color lamps found in private gardens and individual apartments. In order to facilitate the identification of survey locations by the observers (see Section 2.5), all points were located, where possible, next to local landmarks, such as road signs, lampposts, fire hydrants, staircases or garbage cans (see Appendix B for an example of a description of a typical survey route provided to the participants).

2.3. Instrumental Measurements

Following the International Commission on Illumination (CIE) nighttime illumination measurement methodology and the CIE13201-4 measurement guidelines [41], the following types of measurements (Lux) were performed at each survey location:

- *Point horizontal* measurements were taken at the ground level, while positioning the light-meter horizontally above the ground. It should be noted, that although during the measurements, the measurement device was kept close to the ground, it was elevated by up to 300 mm to a horizontal position, as ensured by a level.
- *Point vertical directional* measurements were taken in the walking direction towards the *next* measurement point along the survey route, at the height of 1.5 m above the ground, as a forward-facing vertical measurement of the illumination of the face of the observer.
- *Point vertical panoramic* measurements of lit surfaces facing the observer were taken at the walking direction to the next point along the survey route, at intervals of about 30°, to cover an angle of about 120°. Measured values were averaged into a single value of wide-angle directional illuminance to represent the level of panoramic illumination of the observer’s face at a given measurement point.

Measurements were performed using a Konica-Minolta CL 200A Chroma-meter [42]. To ensure comparability, all measurements were conducted under clear weather on weekdays, starting at least half an hour after dark and ending before 24:00.

2.4. Mobile Phone Application Used for the Survey

A mobile phone android application—CityLights™ (Figure 6)—was developed *ad hoc* for the survey and uploaded on the Google Play Store. The application could only be accessed by participants who were recruited, registered and authorized by a professional survey agency (see Section 2.5). Authorized observers could use the application, as elaborated below, by first entering their nine-digit IDs into the entrance screen (Figure 6a).

Figure 6. Mobile phone application “CityLights”—sample screens: (a) app enter screen, (b) survey questions screen, (c) survey point redirection screen. See text for a full range of assessment scales.

To avoid a misalliance between the locations of instrumentally measured points and points assessed by the observers, the application was designed to operate *only* at the designated survey points (Figures 2–4). To assist in locating the exact spot, we provided observers with detailed guiding instructions for each route (see Appendix B for an example of instruction pages for a selected survey route). The accuracy of the observer’s position was assured by the mobile phone’s GPS and automatically compared by the CityLights™ app with the location of the designated point. If an observer was off a designated point, the application did not allow to perform the assessment. As confirmed by the post-survey assessments, the accuracy of the observers’ positioning was 12 ± 3.4 m, which is within normal limits of mobile phones’ GPS accuracy [43], thus, indicating that the observers reported from the designated locations.

To enable the use of the application within the desired time-frame, it was designed to operate only from 30 min after sunset until 24:00 (Figure 6a). To avoid duplicate assessments, each observer was allowed to perform assessment only once at any given route, either before 20:00 or after 20:00, which represent early and late evening hours. To avoid interference, observers were instructed to arrive at a particular survey route and conduct the assessments alone, without being accompanied by any other person, and only at a particular time-frame designated in advance.

After entering the app, the observer was asked, at each survey point, to use a 4-point scale, also known as “forced” Likert scale, to assess four light attributes, FoS and overall comfort, using the following scales. The decision to use such a scale was based on accumulated knowledge

which indicates that the absence of a “neutral” option forces an observer to make a definite assessment [44]. The particular scales used for assessing different parameters were as follows:

- (a) Illuminance (0—very weak; 1—reasonable; 2—good; 3—too strong);
- (b) Light temperature (0—too cold; 1—a bit cold; 2—a bit hot; 3—too hot);
- (c) Light uniformity (0—non-uniform; 1—slightly non-uniform; 2—quite uniform; 3—very uniform);
- (d) Light glare (0—not glaring; 1—slightly glaring; 2—quite glaring; 3—very glaring);
- (e) Feeling of safety (0—feel very unsafe; 1—feel little unsafe; 2—feel reasonable safe; 3—feel very safe).
- (f) Overall lighting quality (0—uncomfortable; 1—slightly uncomfortable; 2—quite comfortable; 3—very comfortable).

The application transmitted real time assessments to a designated cloud server, from which the information was subsequently downloaded for the analysis. In addition to reporting through the app (see Section 2.4), observers were requested to fill in a short questionnaire on their individual characteristics, such as age, gender, education, place of residence, and ethnic background.

Following our focus in this paper on *FoS-PSL association*, only illuminance (Question 1) and FoS parameters (Question 5) were used in the following analysis as independent and dependent variables, respectively. Other parameters, i.e., overall lighting quality, light temperature, glare and uniformity—are meant to be investigated in follow up studies.

2.5. Survey Participants

Observers were recruited by *Dialog Ltd.* agency, specializing in sociological surveys and research [45]. In each investigated city, the group of observers was comprised of residents and non-residents, representing the local population in terms of age and gender. A total of 106 observers participated in the survey, assessing 257 survey points, at different hours of the evening, in 10 neighborhoods. Thirty-six observers performed assessments in Tel Aviv-Yafo, forty-three in Haifa, and twenty-seven in Be'er Sheba. The survey started in August 2019, and its results (7255 individual assessments) were downloaded from the application server on October 29th, 2019, for future processing. Table 2 reports descriptive statistics of the research variables.

2.6. Statistical Analysis

For each point, FoS data were averaged (Total = 257) and matched with instrumentally measured PSL attributes (see Section 2.3). To reveal the association between FoS levels—used as a *dependent variable*—and instrumentally measured illuminations levels and several locational confounders (city, vegetation density and traffic intensity), the following generic equation was used:

$$FoS_i = b_0 + b_1 \cdot IL_{ji} + b_2 \cdot VDi + b_3 \cdot Tli + \varepsilon_i, \quad (1)$$

where FoS_i is an average FoS assessment of survey point i ; IL_{ji} is a vector of j illuminance measurements (point horizontal, point vertical directional, and vertical panoramic), taken at point i (see Section 2.3); VDi —vegetation density, assessed by the researchers on a 3-point scale (0—trees and shrubs that do not obscure street lights; 1—trees and shrubs partially obscuring street lights; and 2—trees and shrubs significantly obscuring street lights); Tli —traffic intensity during experimental measurements assessed by the researchers on a 3-point scale (0—less than five vehicles in 15 min; 1—5–10 vehicles in 15 min; and 2—more than 10 vehicles in 15 min); and ε_i —random error term.

It should be pointed out, that empirical literature comments on vegetation as a factor framing the view [46–48], while traffic is known to affect FoS in two ways: by car headlights contributing to dynamic street lighting, and by cars at night perceived by pedestrians as a source of danger [49]. Therefore, these two factors were considered in the present analysis as potential confounders.

To monitor the degree of multi-collinearity between the explanatory variables, we used the variance inflation factor (VIF), and did not simultaneously introduce into the model's variables for which VIF

exceeded a predefined threshold ($VIF > 3.0$) [50]. Although different combinations of control variables were tested, only the best performing models are reported in the following discussion. The analysis was performed in the SPSS 25.0TM software [51].

3. Results

3.1. General Trends

Table 2 shows that, on the average, the illumination levels in the survey neighborhoods are close to the illuminance level of 15 Lux, recommended by CIE (2010), reaching about 18.52 Lux for point horizontal measurements; 11.92 Lux for vertical panoramic measurements, and 11.37 Lux for vertical directional measurements. The reported average FoS level in the surveyed cities is also relatively high—1.89 points on a 4-point scale, in compare to the *average* on the adopted scale (1.5 points).

Table 2. Selected descriptive statistics of research variables.

Variable/Units/Measurement Method	No. of Observation Points	Minimum	Maximum	Mean	SE
FoS on a 4-point Likert scale (from 0-low to 3-high)					
• Tel Aviv-Yafo	107	1.15	2.43	1.89	0.03
• Haifa	73	1.42	2.62	2.07	0.03
• Be'er Sheba	77	0.86	2.42	1.75	0.05
Illumination (Lux)					
A. Point horizontal	257	0.47	199.96	18.52	1.58
• Tel Aviv-Yafo	107	0.47	199.85	20.08	2.40
• Haifa	73	0.78	97.36	18.02	1.79
• Be'er Sheba	77	0.50	64.91	16.84	1.58
B. Point vertical panoramic	257	0.43	284.46	11.92	1.24
• Tel Aviv-Yafo	107	0.43	284.46	13.05	2.78
• Haifa	73	0.82	21.45	8.95	0.62
• Be'er Sheba	77	0.54	52.48	13.17	1.24
C. Point vertical directional	257	0.61	183.19	11.37	1.04
• Tel Aviv-Yafo	107	0.61	183.19	12.34	1.92
• Haifa	73	0.69	26.83	8.62	0.79
• Be'er Sheba	77	0.69	37.43	12.64	1.04

3.2. Association between FoS and Illumination Levels

Table 3 reports results of a non-parametric Mann–Whitney U-test that compares FoS across differently illuminated areas. As the table shows, significant differences in FoS levels are present in respect to both mean and median breakdowns of the illumination levels ($M-W > 3200$, $p < 0.01$), thus, indicating that FoS assessments tend to be *significantly higher* in well-illuminated locations than in poorly illuminated ones.

3.3. Multivariate Analysis

Tables 4 and 5 report regression models linking different illumination measures with FoS. Table 4 reports bivariate regression, based on original and logarithmically transformed values of the illumination variable, while Table 5 features multiple regression models, into which city dummies, vegetation and traffic density are introduced as controls.

Table 3. Differences in FoS between differently lit areas (Method—Mann-Whitney U-test for differences, based on mean and median levels of illumination [lux]).

Value Breakdown/Measurement Method/Illumination Range	Average FoS Assessment on a 4-Point Likert Scale—from 0 (Low) to 3 (High)	Mann-Whitney U-test and Significance Level
A. Mean values		
Point horizontal		
• Low (<18.52 Lux)	1.77	3205.50 *
• High (>18.52 Lux)	2.12	
Point vertical panoramic		
• Low (<11.92 Lux)	1.80	4096.00 *
• High (>11.92 Lux)	2.07	
Point vertical directional		
• Low (<11.37 Lux)	1.80	4344.00 *
• High (>11.37 Lux)	2.07	
B. Midian values		
Point horizontal		
• Low (<13.42 Lux)	1.71	3364.50 *
• High (>13.42 Lux)	2.08	
Point vertical panoramic		
• Low (<7.85 Lux)	1.75	4440.50 *
• High (>7.85 Lux)	2.04	
Point vertical directional		
• Low (<8.17 Lux)	1.78	5185.50 *
• High (>8.17 Lux)	2.01	

* indicates a 0.01 significance level.

Table 4. Association between illuminance levels measured by different methods (Lux) and FoS (method—bivariate OLS regression; dependent variable—average values of FoS on a 4-point Likert scale—from 0 (low) to 3 (high))^a.

Illumination Level/Measurement Method	B ^b	Beta ^c	t-Stat ^d	B ^b	Beta ^c	t-Stat ^d	B ^b	Beta ^c	t-Stat ^d
A. Explanatory variables measured on original continuous scales (Lux)									
	Model 1A			Model 1B			Model 1C		
• (Constant)	−0.34	-	−4.17 *	−0.13	-	−1.81 *	−0.44	-	−4.42 *
• Point horizontal	0.02	0.35	6.05 *	-	-	-	-	-	-
• Point vertical—panoramic	-	-	-	0.01	0.21	3.48*	-	-	-
• Point vertical—directional	-	-	-	-	-	-	0.03	0.33	5.49 *
• R2	0.13			0.05			0.11		
• F	36.65 *			12.11 ***			30.14 *		
B. Explanatory variables are logarithmically transformed									
	Model 1D			Model 1E			Model 1F		
• (Constant)	−1.45	-	−10.12 *	−0.93		−7.50 *	−0.86	-	−6.33 *
• Point horizontal	0.58	0.56	10.85 *	-	-	-	-	-	-
• Point vertical—panoramic	-	-	-	0.47	0.47	8.40 *	-	-	-
• Point vertical—directional	-	-	-	-	-	-	0.43	0.40	6.70 *
• R2	0.32			0.21			0.16		
• F	117.73 *			70.37 *			48.56 *		

^a z-score normalized ($\mu = 1.90$, $SD = 0.37$); ^b unstandardized regression coefficient, ^c standardized regression coefficients, ^d t-statistic and its significance value, *, **, *** indicates a 0.01, 0.05 and 0.1 significance levels, respectively.

As Table 4 shows, among the models based on the three illumination measurements—point horizontal, point vertical directional, and point vertical panoramic—the model incorporating *point-horizontal* measurements provides the best results, as indicated by model fit and generality ($R^2 = 0.13$, $F = 36.65$ in Model 1A vs. $R^2 = 0.05$, $F = 12.11$ in Model 1B and $R^2 = 0.11$, $F = 30.14$ in Model 1C). The *logarithmic transformation* of the original illumination scale further improves the model fit and generality, raising them to $R^2 = 0.32$ and $F = 117.73$, respectively (see Model 1D). This model improvement indicates that the relationship between FoS and illumination is, in fact, *non-linear*.

Table 5. Factors affecting FoS (Method—multiple OLS regression) ^a.

Predictors	Model 2			Model 3			Model 4			
	B ^b	Beta ^c	t-stat ^d	B ^b	Beta ^c	t-stat ^d	B ^b	Beta ^c	t-stat ^d	VIF ^e
(Constant)	−1.45	−	−0.12 *	−1.20	−	−8.30 *	−1.17	−	−7.67 *	−
Illuminance (ln) (Lux)	0.58	0.56	10.85 *	0.53	0.51	9.93 *	0.51	0.49	10.21 *	1.11
Vegetation density (0–2) ^f	−	−	−	−0.34	−0.23	−4.67 *	−0.282	−0.19	−3.96 *	1.12
Traffic intensity (0–2) ^g	−	−	−	0.20	0.14	2.64 *	0.228	0.16	3.18 *	1.12
City dummies (reference = Tel Aviv-Yafo):										
• Haifa	−	−	−	−	−	−	0.323	0.15	2.76*	1.33
• Be'er Sheba	−	−	−	−	−	−	−0.421	0.19	−3.79*	1.24
R ²	0.32			0.39			0.47			
Adjusted R ²	0.31			0.39			0.46			
F	117.73 *			54.55 *			45.02 *			
R ² Change	−			0.08			0.08			
F Change	−			16.02 *			19.02 *			

^a z-score normalized ($\mu = 1.90$, $SD = 0.37$); ^b unstandardized regression coefficient, ^c standardized regression coefficients, ^d t-statistic and its significance value, * indicates a 0.01 significance levels, ^e variance inflation factor (multi-collinearity text), ^f vegetation density coding: 0—trees and shrubs do not obscure street lights; 1—trees and shrubs partially obscure street lights; 2—trees and shrubs significantly obscure street lights; ^g traffic intensity coding: 0—small number of vehicles during experimental measurements (less than 5 per 15 min); 1—average number of vehicles during experimental measurements (5–10 vehicles per 15 min); 2—large number of vehicles during experimental measurements (more than 10 per 15 min). **Model 2:** Horizontal ground-level illumination as explanatory variable only; **Model 3:** vegetation density and traffic intensity assessments added; **Model 4:** city dummies added.

Characteristically, in all models, FoS was found to be significantly and positively related to illumination ($B = 0.02$, $t = 6.05$, $p < 0.01$; Model 1A and $B = 0.58$, $t = 10.85$, $p < 0.01$; Model 1D), indicating that the observers perceive areas with higher illumination as safer. However, the observed improvement in the model fit, attributed to the logarithmic transformation of the illumination variable, indicates that there are *diminishing FoS returns*, as *increasing illumination to high levels leads to smaller and smaller improvements in FoS*.

Multiple regression models, reported in Table 5, leave the linkage between FoS and illumination generally unchanged ($B = 0.53$, $t = 9.93$, $p < 0.01$ in Model 3 vs. $B = 0.51$, $t = 10.21$, $p < 0.01$ in Model 4), but control variables in the latter model—city, traffic and vegetation density—emerge in this model as statistically significant ($p < 0.01$). In particular, as Model 4 shows, all else held equal, traffic increases the average FoS level by 0.23 points on a 4-point scale ($B = 0.23$, $t = 3.18$, $p < 0.01$; Model 4), while obscuring vegetation decreases it by of 0.28 points ($B = −0.28$, $t = −3.96$, $p < 0.01$; Model 3).

City dummies in Model 4 (see Table 5) are also statistically significant ($p < 0.01$), but appear to have different directions, being positive for Haifa ($B = 0.32$, $t = 2.76$, $p < 0.01$) and negative for Be'er Sheba ($b = −0.42$, $t = −3.79$, $p < 0.01$). This indicates that when all other factors held equal for a *given level of illumination*, the observers tend to feel *safer* by about 0.3 points in Haifa than in Tel Aviv-Yafo (the reference city in the analysis), and by 0.4 points *less safe* in Be'er Sheba than in Tel Aviv-Yafo.

3.4. Model-Response Test

Figure 6 reports the results of model-estimated FoS-response test to plausible changes in illumination levels. This test is based on Model 4 in Table 5. To run this test, the values of all variables (except for illumination) were set to their average levels, while the level of illumination was allowed to vary in a plausible range, between 0 and 50 Lux.

As Figure 7 shows, to achieve the average FoS level of 1.89 observed in Tel Aviv-Yafo, the level of illumination, E_{av} , should reach 5.67 Lux in Haifa and 24.46 Lux in Be'er Sheba. Concurrently, to achieve the average FoS level of Haifa (FoS = 2.07), E_{av} in Tel Aviv-Yafo should reach 28 Lux and more than 50 Lux in Be'er Sheba. Characteristically, for all three cities, the simulation test shows leveling-off of the FoS response curves, which indicates declining FoS increments for higher levels of street illumination.

Figure 7. FoS model-response test to plausible changes in illuminance (see text for explanations). (A–C)—intersection points between average FoS (1.89 on a 0 to 3 four-point Likert scale), equal to that of Tel Aviv-Yafo (see dotted green line) and estimated PSL sufficiency curves for Haifa, Tel Aviv-Yafo and Be'er Sheba; (D)—intersection point between the estimated PSL sufficiency curve and average FoS level in Be'er Sheba (1.75 on a 0 to 3 four-point Likert scale); (E)—intersection point between the estimated PSL sufficiency curve and average FoS level in Haifa (2.07 on a 0 to 3 four-point Likert scale).

4. Conclusions and Discussion

Previous studies established that efficient and properly designed PSL can reduce energy waste, while making people feel safer [25–28]. However, as the present study shows, higher levels of illumination *do not* necessarily imply an equal rise in FoS. In particular, our analysis indicates that reasonably high assessment of FoS may occur at relatively low illumination levels of 5–10 Lux, and that increasing illumination levels beyond this threshold may result only in a minor rise in FoS levels.

This result confirms [52] that the conclusion “the brighter—the better” is a common misconception, which may lead to unnecessary energy waste. Various reports indicate that street lighting is one of the largest energy consumers, accounting for about 40% of outdoor energy consumption [53,54], and that energy efficient technologies and design can cut street lighting costs by 25–60% [55]. However, a tradeoff should be reached between a need to save energy and secure people’s FoS in urban areas, as poor lighting can create unsafe conditions, and consequently reduce the quality of life and residential satisfaction.

Differences between urban areas should also be considered. As the present analysis shows, the illumination level required by urban residents to feel safe after dark differs across urban areas. In particular, to achieve the same FoS level of 1.89 points on a 4-point scale, from 0 (Low) to 3 (High), observed in the entire sample, much higher levels of illumination appear to be required, other factors being equal, in the southern city of Be’er Sheba (24.46 Lux) than in the northern city of Haifa (5.67 Lux). These results correspond to recent findings of the ICBS’s [56] survey, according to which the percent of adults who feel *unsafe* while walking alone on the streets after dark is the highest in Be’er Sheba (24.6%), compared to 19.4% in Tel Aviv-Yafo and 15.7% in Haifa. These differences may be attributed to Be’er Sheba’s relatively low SES and somewhat higher crime rates (Table 1), and, possibly, also to stronger daylight that the residents of Be’er Sheba are accustomed to, and, therefore, may prefer higher nighttime illumination levels.

The differences in the required nighttime illumination, thus, indicate that the “one-size-fits-all” principle, when applied to nighttime lighting in various urban settings, is another *misconception*. Excessive lighting may lead to energy waste, while insufficient lighting may reduce FoS. The economic aspect is also important, since scale effects turn even small energy savings in different locations to a significant decrease in the total operational costs [49].

The research is novel in several respects. First and foremost, the study was conducted in real-world conditions and accounted for differences between urban settings. During the years, several attempts have been made to investigate the association between street lighting and FoS. However, these studies were mostly conducted in controlled or laboratory conditions, which do not allow accounting for complex environmental conditions. Additionally, the study covered a relatively large number of observation points (257), in 10 different neighborhoods, in three different cities—all of which contribute to higher generality. It should also be noted that previous studies involved relatively small numbers of research subjects, and evaluated relatively small numbers of lighting sources, thus, falling short of representing different urban settings, larger populations and population subgroups [1,29,33,57]. The present study effectively addresses these drawbacks and may lead the way for future studies to be conducted elsewhere. Last but not least, the present study developed and employed a mobile phone location- and time-based application through which pedestrians could report their assessments of perceived PSL attributes and safety. This interactive technology offers a more accurate, reliable and efficient alternative to the “pen and paper” methodologies used in most previous studies.

Several limitations of the present study should, nevertheless, be mentioned. First and foremost, the study reports *aggregated* values of FoS assessments, which may vary between observers according to their individual attributes, specifically gender, which is known to affect FoS [24]. As individual attributes were collected and stored in the research database, follow up studies should attempt to incorporate them into the analysis, by using models that are based on individual observations, instead of ordinary least square regressions based on average assessments, such as those used in this study. Furthermore, while the present analysis solely focuses on *illuminance*, follow up studies should look into other lighting attributes, such as glare, uniformity, light temperature, etc. Future studies, using the proposed methodology and carried out elsewhere, can also contribute to the understanding of the robustness and generality of this study’s results, and ultimately facilitate the development of guidelines for other cities.

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interpretation and assisted with paper writing. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Selected characteristics of the neighborhoods surveyed.

Neighborhood (See Figures 2–4 for Neighborhood Maps and Location)	Nighttime Illumination Group—Predominant Wavelength and Illuminance Level	Street Lighting Class (According to CIE 13201)	Population Density per SCA ^a	SES Index on a 20-Point Scale from 1 (Low) to 20 (High) ^a
Tel Aviv-Yafo				
Neve Avivim (NA)	RL, BL	P2	19.35	17.00
Nahalat Yitshak (NY)	BH	P1, C0	30.00	14.00
HaTsafon HaHadash Center (C)	RH	P1	20.49	17.00
Ramat Aviv HaHadasha (RAH)	RL	P1	n/a	n/a
Haifa				
Ramat Ben Gurion (RBC)	RL, BL	C3	11.19	17.00
Yizra'eliya (Y)	RH	C2	16.59	12.00
Neot Peres (NP)	BH	P1	n/a	n/a
Be'er Sheba				
Yud-Alef (YA)	RL, BL	P1	10.85	8.00
Tet (T)	BH	P1	10.50	12.00
Never Ze'ev (NZ)	RH	P1, C3	20.31	10.00

RL = red low; BL = blue low; RH = red high; BH = blue high; n/a = not available; ^a. On an ordinary scale used by Reference [57] for small census areas—from 1 (Low) to 20 (High).

Appendix B

Example of instructions provided to the observers. Neighborhood name: Ramat Ben Gurion (SCA 4000911), Haifa; Main Street–Oren; Internal Streets–Oren.

(a)

Figure A1. Cont.

(b)

Figure A1. (a) Survey route with survey points marked; (b) survey point #1.**Table A2.** Description of the survey points along the survey route example.

Point #	Description
RBG1	A bench next to the corner of the Oren St, 5 building (the first house on the left side of the road), near an anti-dog poop sign. Across the street, there is a kindergarten located above the street level.
RBG 2	Next to the utility box on the sidewalk, adjacent to the low fence, between Oren St. 5 and 7
RBG 3	On the entrance to the stairways going down into the empty lot between Oren St, 7 and 9, near the garbage cans and under the lamp post.
RBG 4	Next to the utility box on the sidewalk, adjacent to the low fence, between Oren St, 9 and 11, under a lamp post, but dark because of overhanging trees;
RBG 5	Next to the fire hydrant between Oren St, 11 and 13.
RBG 6	Next to the entrance to Oren St, 13
RBG 7	Near a high voltage power line pole and to the entrance to the staircase going down to an empty lot; on the other side of the road there is a single very high light pole;
RBG 8	At a bench left to the entrance to Oren St, 15
RBG 9	Next to the recycle point between Oren St, 15 and 17, under a lamp post
RBG 10	Near the entrance to a stairway going down to an empty lot between Oren St, 17 and 19
RBG 11	Next to the entrance to Oren 19
RBG 12	Near the sign "Green Path"
RBG 13	At a bench near the reserved parking for the car #5026132, at the entrance to Oren st, 21
RBG 14	Cross the road in the direction of the cage for collecting plastic bottles. The assessment spot is next to the cage
RBG 15	Continue uphill for about 20 m. The measurement point is next to the fire hydrant to your left, near the corner of the first house encountered
RBG 16	Next to the entrance to Oren st, 23

Table A2. Cont.

Point #	Description
RBG 17	At a bench in the background the shopping promenade and an the “Oren Clinic” sign
RBG 18	Next to the charging unit No 046 for electric cars (car-to-go)
RBG 19	At the Shufersal shopping centre’s cart collection spot, near the entrance to the supermarket
RBG 20	Near the “Neighborhood Billboard” stand, opposite to the shopping center’s blank wall
RBG 21	Near the fire hydrant under a lamp post, <i>opposite</i> the shopping center building’s farer corner (do not cross street towards the parking lot, stay on the same pathway)
RBG 22	A bench near before the entrance to Oren St, 31, near a small street level garden with upward directed color spotlights lighting young trees
RBG 23	Near the ramp to the Oren St 31, building (two benches and a shack, before crossing the street)
RBG 24	A bench to the left side of the school entrance, near a “Romema” library sign; the bench overlooks a parking lot
RBG 25	A bench near the path leading to the kindergarten “Romema”, at the corner of the school neighboring the parking lot

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