A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP14414.

Comparing Data from Three Satellites on Artificial Light at Night (ALAN): Focusing on Blue Light's Influence on Colorectal Cancer in a Case–Control Study in Spain

Barbara N. Harding,[1,2,3] Anna Palomar-Cros,[1,2,3,4] Antonia Valentín,[1,2,3,5] Ana Espinosa,[1,2,3,5] Alejandro Sánchez de Miguel,[6,7] Gemma Castaño-Vinyals,[1,2,3,5] Marina Pollán,[3,8] Beatriz Perez,[3,8] Victor Moreno,[3,9,10,11] and Manolis Kogevinas[1,2,3,5]

[1]Barcelona Institute for Global Health (ISGlobal), Barcelona, Spain
[2]Universitat Pompeu Fabra (UPF), Barcelona, Spain
[3]CIBER Epidemiology and Public Health (CIBERESP), El Instituto de Salud Carlos III (ISCIII), Madrid, Spain
[4]Fundació Institut Universitari per a la Recerca a l'Atenció Primària de Salut Jordi Gol i Gurina (IDIAPJGol), Barcelona, Spain
[5] Hospital del Mar Medical Research Institute (IMIM), Barcelona, Spain
[6]Environment and Sustainability Institute, University of Exeter, Penryn, UK
[7]Departamento Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, Madrid, Spain
[8]Department of Epidemiology of Chronic Diseases, National Centre for Epidemiology, Instituto de Salud Carlos III, Madrid, Spain
[9]Oncology Data Analytics Program, Catalan Institute of Oncology (ICO), L'Hospitalet de Llobregat, Spain
[10]Colorectal Cancer Group, ONCOBELL Program, Institut de Recerca Biomedica de Bellvitge (IDIBELL), L'Hospitalet de Llobregat, Spain
[11]Department of Clinical Sciences, Faculty of Medicine and health Sciences and Universitat de Barcelona Institute of Complex Systems (UBICS), University of Barcelona (UB), L'Hospitalet de Llobregat, Spain

https://doi.org/10.1289/EHP14414

Introduction

Artificial light-at-night (ALAN) exposure alters circadian rhythms[1] and is associated with a range of adverse health outcomes in humans, including colorectal cancer (CRC).[2] The intrinsically photosensitive retinal ganglion cells (ipRGCs) in the eye are responsible for circadian rhythm regulation and melatonin production[3] and are most sensitive to short wavelengths (i.e., blue light). Exposure to ALAN suppresses the production of melatonin, a hormone that has anticancer functions across tumor initiation, promotion, and progression.[2]

Most investigations in this field have used images from the Defense Meteorological Program Operational Linescan System (DMSP-OLS) or the Visible Infrared Imaging Radiometer Suite (VIIRS), which do not provide information on blue light spectrum and are limited by low spatial resolution (750 m for VIIRS and >1 km for DMSP-OLS).[4] Further, the DMSP-OLS is limited by poor sensitivity at low-level exposures and image saturation at high-level exposures.[5] These limitations are likely to lead to significant exposure misclassification. An advantage of DMSP-OLS is that images are available for a longer time period compared with other satellites.

In a prior study, we examined ALAN exposure in relation to CRC, using images from the International Space Station (ISS), which provided high spatial resolution (30 m) and red-green-blue (RGB) spectral data.[6] In the present study we undertook an analysis of pixel values extracted for each residential address using geographic information system (GIS) data from three satellites (VIIRS, DMSP-OLS, and ISS) and evaluated their associations with odds of CRC with the aim to compare how consistent associations were across exposure data sources.

Methods

Because the ISS images used to evaluate outdoor ALAN were only available in Madrid (2012) and Barcelona (2013), we used data from 768 histologically confirmed incident CRC cases and 1,546 population-based controls from the multicase–control study in Spain (MCC-Spain) (2008–2013)[7] who resided in these cities. CRC-free controls were selected randomly from the rosters of general practitioners at the primary health centers located within these hospitals' catchment areas and were frequency matched to cases by age (in 5-y groups) and study area. The protocol of MCC-Spain was approved by the ethics committees of the participating institutions, and all participants signed informed consent forms. We estimated ISS-based visual ALAN (luminance, cd/cm^2) and an ISS-index of blue light spectrum (melatonin suppression index),[8,9] as well as visual ALAN (radiance, $nW/cm^2/sr$) assessed from DMSP-OLS (2011) and VIIRS (2013). ALAN values from each satellite were assigned to participants' residence at enrollment using GIS. Data on demographic information and lifestyle characteristics were collected through face-to-face interviews, and information on chronotype (diurnal preference for morning/evening) was available from the Munich Chronotype Questionnaire.

We compared visual light estimates using Pearson's correlation coefficient and compared agreement between estimates using (standardized) Bland—Altman plots [limits of agreement equals average difference $\pm$ 1.96 standard deviation (SD) of the standardized difference].[10] We examined linearity of all ALAN measurements using generalized additive models (GAMs) and estimated odds ratios (ORs) for CRC using logistic regression models. Models were adjusted for study area (Barcelona vs. Madrid), age (continuous), sex (male/female), education (highest level achieved: less than primary, primary, secondary, university), body mass index (BMI; continuous), family history of CRC (yes/no), smoking (ever, yes/no), deprivation index (continuous numeric indicator of socioeconomic status), and the World Cancer Research Fund dietary score (continuous). A second set of models also adjusted for night shift work status. Analyses were conducted using RStudio (version 4.0.5; Posit PBC).

Results and Discussion

Participants were on average 64 ($\pm$SD 11) y of age, 54% were male, and 55% reported ever smoking. When examining the distribution of participant characteristics by blue light exposure tertiles (low, medium or high), we saw that a greater proportion of CRC cases had blue light exposure in the high tertile (41%) in

Address correspondence to Barbara N. Harding. Email: barbara.harding@isglobal.org

ASM serves as a consultant for Savestars Consulting S.L. All other authors declare they have nothing to disclose.

Conclusions and opinions are those of the individual authors and do not necessarily reflect the policies or views of EHP Publishing or the National Institute of Environmental Health Sciences.

Note to readers with disabilities: *EHP* strives to ensure that all journal content is accessible to all readers. However, some figures and Supplemental Material published in *EHP* articles may not conform to 508 standards due to the complexity of the information being presented. If you need assistance accessing journal content, please contact ehpsubmissions@niehs.nih.gov. Our staff will work with you to assess and meet your accessibility needs within 3 working days.

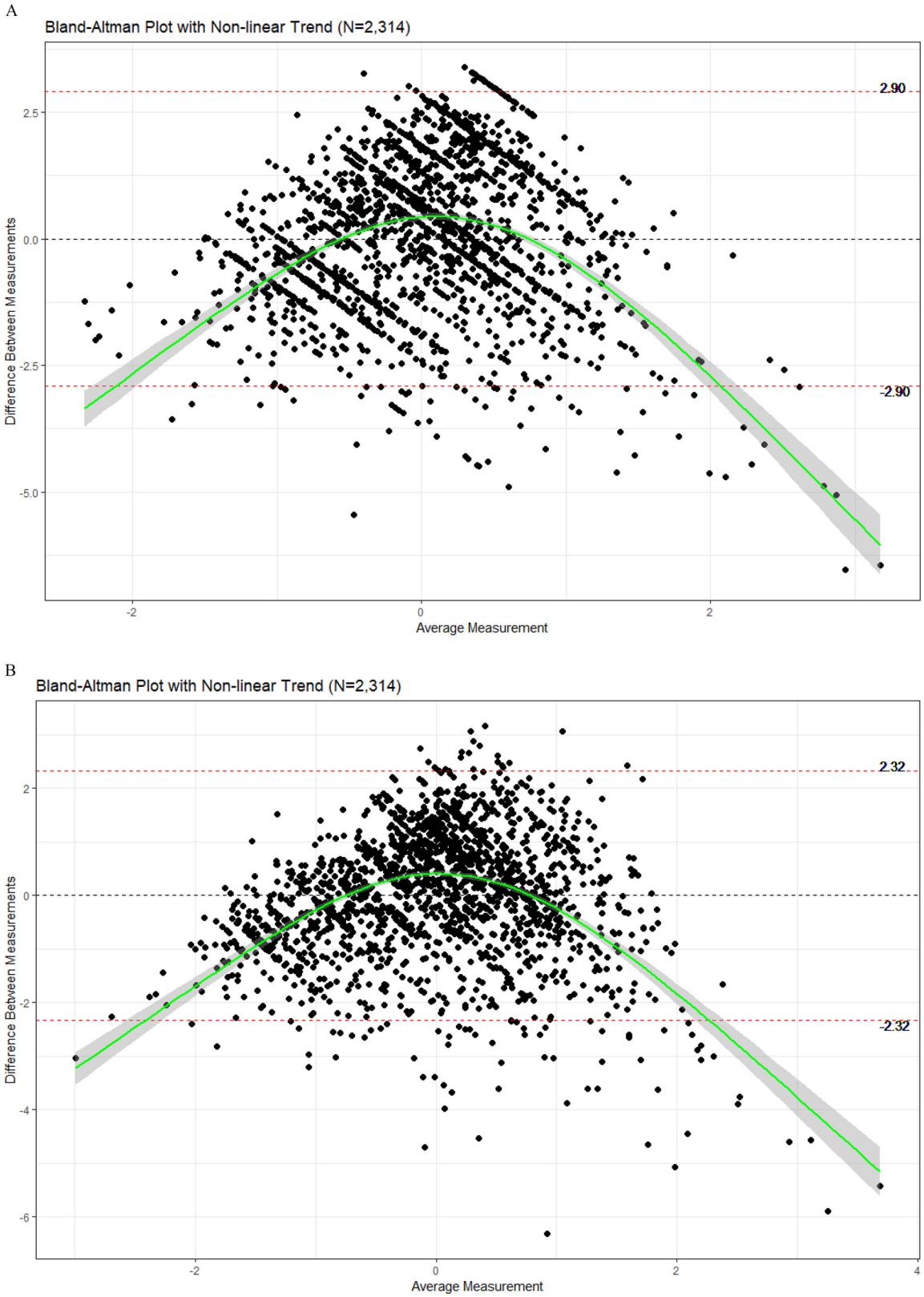

Figure 1. Bland–Altman plots with nonlinear trend for bias (green solid line) including confidence intervals (gray shading) using generalized additive models to compare artificial light at night measurements for (A) visual light from the DMSP-OLS 2011 vs. visual light from the International Space Station (ISS; 2012 Madrid; 2013 Barcelona) and (B) visual light from the VIIRS 2013 vs. visual light from the ISS (2012 Madrid; 2013 Barcelona). The black dots represent data values for each participant. The limits of agreement (average difference $\pm$ 1.96 SD of the standardized difference) are shown by the red dashed lines in each of the figures. Additional data for these plots can be found at https://github.com/barbara-harding/ALAN-satellites-comparison. Note: CI, confidence interval; DMSP-OLS, Defense Meteorological Program Operational Linescan System; ISS, International Space Station; SD, standard deviation; VIIRS, Visible Infrared Imaging Radiometer Suite.

Table 1. Association of ALAN exposure with colorectal cancer in Madrid and Barcelona: estimates reported from light exposure assessed from blue light spectrum-ISS, visual-ISS, visual-DMSP, and visual-VIIRS.

	Model 1 results[a]					Model 2 results[b]				
				95% CI					95% CI	
Satellite measure	Case $n = 686$	Control $n = 1,380$	OR	Lower	Upper	Case $n = 457$	Control $n = 1,239$	OR	Lower	Upper
Blue light ISS (melatonin suppression index)										
First tertile (0.000–0.007)	151	465	1 (Ref)	—	—	121	453	1 (Ref)	—	—
Second tertile (0.008–0.011)	212	462	1.20	0.90	1.59	139	407	1.34	0.97	1.83
Third tertile (0.0112–0.042)	323	453	1.83	1.38	2.44	197	379	2.20	1.58	3.05
Visual light ISS (luminance, cd/m^2)										
First tertile (0.000–0.134)	267	465	1 (Ref)	—	—	174	413	1 (Ref)	—	—
Second tertile (0.135–0.173)	188	469	0.66	0.52	0.84	127	421	0.66	0.50	0.88
Third tertile (0.174–0.401)	231	446	0.89	0.70	1.13	156	405	0.84	0.63	1.11
Visual light DMSP (radiance, nW/cm^2/sr)										
First tertile (80.0–574.7)	287	465	1 (Ref)	—	—	178	416	1 (Ref)	—	—
Second tertile (577.1–669.1)	157	514	0.97	0.73	1.28	112	500	0.82	0.59	1.14
Third tertile (669.9–917.1)	242	401	1.33	1.05	1.70	167	323	2.10	1.56	2.82
Visual light VIIRS (radiance, nW/cm^2/sr)										
First tertile (12.4–107.7)	263	492	1 (Ref)	—	—	176	456	1 (Ref)	—	—
Second tertile (107.8–124.8)	196	438	0.70	0.55	0.90	137	368	0.74	0.56	0.99
Third tertile (124.9–164.2)	227	450	0.63	0.49	0.81	144	415	0.52	0.39	0.70

Note: The range of values for each tertile are presented for each satellite type. ORs and 95% CIs were estimated for odds of colorectal cancer using logistic regression models adjusted for relevant confounders. —, no data; ALAN, artificial light at night; CI, confidence interval; DMSP-OLS, Defense Meteorological Program Operational Linescan System; ISS, International Space Station; OR, odds ratio; Ref, reference; sr, steradian; VIIRS, Visible Infrared Imaging Radiometer Suite.

[a]Model 1 adjusts for: study area, age, sex, education, body mass index (categorical), family history of colorectal cancer, smoking (ever, yes/no), deprivation index (a numeric national indicator of socioeconomic status), and a World Cancer Research Fund dietary score ($n = 248$ with missing data on ≥1 covariate from model 1).

[b]Model 2 additionally adjusted for night shift work ($n = 370$ were missing data on night shift work status).

comparison with the low and medium tertiles (25% and 32%, respectively) and in the highest category of blue light exposure there were fewer morning type chronotypes (23% in comparison with 36% and 29% for low and medium, respectively).

Given the different spatial resolutions of the satellite-based data, we counted 625 cells from the ISS in a single cell of the VIIRS and more than 1,100 from the ISS in a single cell of the DMSP. Both VIIRS and DMSP-OLS assessed only visual light. We found that both sources underestimated visual ALAN when compared with the ISS values. There was an observable pattern of disagreement from the Bland–Altman Plots (Figure 1). The limits of agreement for the DMSP-OLS vs. ISS-visual measurements was 2.90 [95% confidence interval (CI): 2.80, 3.01], whereas for the VIIRS vs. ISS-visual it was 2.32 (95% CI: 2.24, 2.41). The smaller disagreement limits for the VIIRS-ISS comparison indicates slightly better agreement between these satellite-based measurements. In addition, in both cases (DMSP-OLS vs. ISS-visual and VIIRS vs. ISS-visual), we saw that at both low and higher average light levels, the difference between the measurements was larger, indicating that the DMSP-OLS and VIIRS methods underestimated light exposure at these extremes when compared with the ISS-visual light measurements. There was poor correlation between the three sources of visual ALAN data (DMSP-OLS vs. ISS $R^2 - 0.10$, VIIRS vs. ISS R^2 0.30, DMSP-OLS vs. VIIRS R^2 −0.15).

From the GAMs, we found evidence of a deviation from linearity and therefore categorized light exposure in tertiles to determine ORs for low (reference) vs. moderate or high levels of exposure. In primary models, we found an association between the ISS blue light exposure and CRC (OR = 1.83; 95% CI: 1.38, 2.44) for the highest tertile of light exposure. The association using the ISS-visual light measurement was less consistent. We found no association for the highest tertile of ISS-visual light exposure and an inverse relationship for those with a moderate light exposure level (OR = 0.66; 95% CI: 0.52, 0.84). Using visual light measured from the DMSP-OLS, we found a higher odds of CRC (OR = 1.33; 95% CI: 1.05, 1.70) for the highest tertile of light exposure, whereas the estimates from the VIIRS suggested an inverse effect of moderate (OR = 0.70; 95% CI: 0.55, 0.90) and high levels of visual light exposure (OR = 0.63; 95% CI: 0.49, 0.81). Even after adjusting for night shift work, results remained consistent but with higher odds of CRC for the highest tertiles of ISS blue light and DMSP visual light (Table 1).

This analysis showed that the type of satellite-based light measurement impacted the effect estimates for odds of CRC. Based on the primary hypothesized mechanism between light, circadian disruption, and cancer risk, and considering the other characteristics of each of the three satellite types (resolution, saturation, sensitivity), we hypothesize that the best estimate is that provided by the ISS blue light exposure, which indicated a 1.8-fold odds of CRC for those with the highest tertile of blue light exposure. It is challenging to reconcile the differences in results from each satellite; however, we expect that exposure misclassification resulting from limited resolution would likely result in nondifferential misclassification, whereas image saturation could result in differential misclassification. We deduce that there is simply too much noise (exposure misclassification) with low resolution and saturated images and that color is undeniably important. Together these may result in unexpected findings.

In conclusion, future epidemiological studies should focus on newer satellite-based technologies that provide light spectra–based estimates most relevant to circadian disruption and should limit the use of low spatial resolution data when there is interest in assigning ALAN exposures at the address level. Beyond this, future studies should also attempt to move away from a reliance solely on satellite-based technologies, because the few studies that have examined correlation between personal light-based measurements (e.g., sensors, questionnaires) fail to show a strong, or even moderate, correlation with the satellite-based exposure.

Acknowledgments

ISGlobal acknowledges support from the Spanish Ministry of Science and Innovation through the "Centro de Excelencia Severo Ochoa 2019–2023" Program (CEX2018-000806-S) and support from the Generalitat de Catalunya through the CERCA Program. B.H. has received funding from the Instituto de Salud Carlos III (ISCIII) and the European Union NextGenerationEU/PRTR (grant IHMC22/00017). V.M. has received funding from the

Instituto de Salud Carlos III, cofunded by ERDF "A Way of Making Europe" (grant PI17-00092); from the Spanish Association Against Cancer (AECC) Scientific Foundation (grant GCTRA18022MORE); and from the Consortium for Biomedical Research in Epidemiology and Public Health (CIBERESP) (action Genrisk).

Data are available from the authors with reasonable request. Relevant analysis code can be found on GitHub (https://github.com/barbara-harding/ALAN-satellites-comparison).

References

1. Bedrosian TA, Nelson RJ. 2017. Timing of light exposure affects mood and brain circuits. Transl Psychiatry 7(1):e1017, PMID: 28140399, https://doi.org/10.1038/tp.2016.262.
2. Schernhammer ES, Laden F, Speizer FE, Willett WC, Hunter DJ, Kawachi I, et al. 2003. Night-shift work and risk of colorectal cancer in the Nurses' Health Study. J Natl Cancer Inst 95(11):825–828, PMID: 12783938, https://doi.org/10.1093/jnci/95.11.825.
3. Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner E, et al. 2001. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. J Neurosci 21(16):6405–6412, PMID: 11487664, https://doi.org/10.1523/JNEUROSCI.21-16-06405.2001.
4. Urbano T, Vinceti M, Wise LA, Filippini T. 2021. Light at night and risk of breast cancer: a systematic review and dose-response meta-analysis. Int J Health Geogr 20(1):44, PMID: 34656111, https://doi.org/10.1186/s12942-021-00297-7.
5. Kyba CCM. 2016. Defense Meteorological Satellite Program data should no longer be used for epidemiological studies. Chronobiol Int 33(8):943–945, PMID: 27254140, https://doi.org/10.1080/07420528.2016.1189432.
6. Garcia-Saenz A, Sánchez de Miguel A, Espinosa A, Costas L, Aragonés N, Tonne C, et al. 2020. Association between outdoor light-at-night exposure and colorectal cancer in Spain. Epidemiology 31(5):718–727, PMID: 32639250, https://doi.org/10.1097/EDE.0000000000001226.
7. Castaño-Vinyals G, Aragones N, Perez-Gomez B, Martín V, Llorca J, Moreno V, et al. 2015. Population-based multicase-control study in common tumors in Spain (MCC-Spain): rationale and study design. Gac Sanit 29(4):308–315, PMID: 25613680, https://doi.org/10.1016/j.gaceta.2014.12.003.
8. Sánchez de Miguel A, Zamorano J, Aubé M, Bennie J, Gallego J, Ocaña F, et al. 2021. Colour remote sensing of the impact of artificial light at night (II): calibration of DSLR-based images from the International Space Station. Remote Sens Environ 264:112611, https://doi.org/10.1016/j.rse.2021.112611.
9. Sánchez de Miguel A, Kyba CCM, Aubé M, Zamorano J, Cardiel N, Tapia C, et al. 2019. Colour remote sensing of the impact of artificial light at night (I): the potential of the International Space Station and other DSLR-based platforms. Remote Sens Environ 224:92–103, https://doi.org/10.1016/j.rse.2019.01.035.
10. Dogan NO. 2018. Bland-Altman analysis: a paradigm to understand correlation and agreement. Turk J Emerg Med 18(4):139–141, PMID: 30533555, https://doi.org/10.1016/j.tjem.2018.09.001.