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TECHNICAL NOTE

A comprehensive checklist for reporting light characteristics in laboratory-based human studies using light as an intervention

CIE TN 016:2026

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This Draft Technical Note has been prepared by CIE Division Reporter 6-48 of Division 6 “Photobiology and Photochemistry". The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by all with an interest in excellence in light and lighting. The information provided here is advisory and not mandatory.

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This Draft Technical Note has been prepared by the Division Reporter of DR 6-48 “A comprehensive checklist for reporting light characteristics in in-laboratory human studies using light as an intervention”, in cooperation with four co-authors. The Division Reportership comes under Division 6 “Photobiology and Photochemistry”.

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Summary

Small variations in light intensity, spectral quality, or timing during clinical or basic research studies can result in substantial differences in observed responses. Therefore, suitable measurement and reporting practices are becoming increasingly important in lighting research.

The CIE, through initiatives like the publication of CIE S 026/E:2018 “System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light”, played a key role in establishing standards for measuring how different aspects of light affect our eyes. This includes defining specific functions, quantities and metrics to describe how optical radiation stimulates various photoreceptor types, which can influence non-visual effects of light on the human retina through melanopsin-expressing intrinsically photosensitive retinal ganglion cells (ipRGCs). To date, however, there is a lack of consensus within the large community studying the ipRGC-influenced effects of light on humans (i.e. circadian entrainment, pupillary light reflex, etc.) in laboratory-based studies about which characteristics of light to report. As a result, the lack of suitable reporting practices hinders direct comparisons between studies and makes it difficult to draw robust conclusions about the effects of light exposure on human health and well-being.

The ENLIGHT (Expert Network on LIGHT interventions) checklist, described and discussed in this document, has been designed to address this problem, and to assist reviewers, editors and readers to appraise the completeness, applicability and potential for confounds of findings in a study. This document, discussing the ENLIGHT checklist, will provide guidance towards suitable reporting of experimental conditions and light metrics in studies pertaining to ipRGC-influenced light responses in humans. This would directly promote the utilization of the CIE S 026 alpha-opic toolbox whenever α-opic irradiance and/or radiance and α-opic equivalent daylight illuminance (EDI) and equivalent daylight luminance (EDL) are required. Overall this document will complement other CIE documents.

The harmonized reporting of light characteristics described in this document discussing the ENLIGHT checklist will facilitate direct study comparisons and allow for more effective meta-analyses. As neurobiological studies on the ipRGC-influenced effects of light are often resource- and time-intensive, this harmonization would be a crucial advancement for the field. In addition, the ENLIGHT checklist would not only enhance the reliability and credibility of research outcomes but also empower lighting professionals to make informed decisions and advancements in the field. This document discusses the ENLIGHT checklist with the intention to launch the discussion towards further consensus in the community.

1 Introduction

Beyond enabling vision, light exerts powerful effects on our physiology and behaviour (Vetter et al. 2022; Blume et al. 2019). One of the primary non-visual functions of light is to synchronize the central circadian clock (Duffy & Czeisler 2009; Najjar & Zeitzer 2017), in addition to the modulation of pupil size (Lucas et al. 2003), alertness (Lok et al. 2018; Cajochen et al. 2000), mood (Lam et al. 2015) and cognitive brain function (Vandewalle et al. 2009; Lok et al. 2022). These responses to light are mainly mediated by melanopsin-expressing intrinsically photosensitive retinal ganglion cells (ipRGCs) (Aranda & Schmidt 2020; Do 2019; Schmidt et al. 2011) and are therefore referred to as ipRGC-influenced responses, to reflect their distinction from perceptual vision.

IpRGC-influenced effects of light on humans (i.e. circadian entrainment, pupillary light reflex, increasing alertness, etc.) are important factors to be considered towards “healthy” lighting. (Chellappa 2021; Spitschan & Santhi 2022; Phillips et al. 2019). Some quantities and standards pertaining to ipRGC-influenced effects of light on humans were defined in CIE S 026:2018 (CIE 2018), which provides good guidance for researchers in the field. Small variations in light intensity, spectral quality, or timing during clinical or basic research studies can result in substantial differences in observed responses. Therefore, observance of suitable measurement and reporting practices is becoming increasingly important in lighting research. The harmonized

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reporting of light characteristics would enable direct comparisons between studies and facilitate more effective meta-analyses. As neurobiological studies on the ipRGC-influenced effects of light are often resource-intensive and can take years to complete, this harmonization would be a significant advancement for the field.

Several publications have summarized the metrics that are important to report in neurobiological light research and provided recommendations for "healthy" light exposure at different times of the day. To date, however, there is still a lack of consensus within the large community studying the ipRGC-influenced effects of light on humans in laboratory-based studies about which light characteristics to report. Furthermore, in a preliminary examination of peer-reviewed research articles referenced in a recent review paper (Brown 2020) that focused on the ipRGC-influenced effects of light, the ENLIGHT (Expert Network on LIGHT Interventions: ENLIGHT) steering committee[1] discovered that none of these articles uniformly reported essential lighting characteristics such as irradiance, radiance, illuminance, luminance, luminous flux, melanopic quantities, chromaticity, correlated colour temperature (CCT), type of spectrum and peak wavelength (Spitschan et al. 2023). Several proposals for standardized reporting schemes have emerged (Spitschan et al. 2019; Reme et al. 1991; Knoop et al. 2019), including a CIE Technical Note (TN) CIE TN 011:2020 *What to document and report in studies of ipRGC-influenced responses to light* (CIE 2020). None of these have resulted in the generation of a harmonized checklist.

Recently, the ENLIGHT consortium produced a comprehensive checklist for reporting light characteristics in laboratory-based human studies using light as an intervention. The ENLIGHT checklist was developed using a four-step modified Delphi consensus process (Okoli & Pawlowski 2004), including three questionnaire-based feedback rounds and one face-to-face group discussion. This exercise included 65 international participants with experience in laboratory-based studies on ipRGC-influenced responses to light in human participants.

In this document the development and utilization of the ENLIGHT checklist is described and discussed. In addition, it is highlighted how the ENLIGHT checklist and its accompanying explanation and elaboration (E&E) document complement existing CIE publications such as CIE S 026:2018 *System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light* (CIE 2018), CIE TN 012:2021 *Guidance on the Measurement of Temporal Light Modulation of Light Sources and Lighting Systems* (CIE 2021), CIE TN 011:2020 *What to document and report in studies of ipRGC-influenced responses to light* (CIE 2020), CIE TN 004:2016 *The Use of Terms and* Units *in Photometry – Implementation of the CIE System for Mesopic Photometry* (CIE 2016) and CIE 213:2014 *Guide to protocols for describing lighting* (CIE 2014). The ENLIGHT checklist serves as a valuable resource for reviewers, editors and readers, facilitating the assessment of study completeness and applicability, as well as supporting data synthesis across published research. This document also highlights the technological, societal and environmental benefits of the ENLIGHT checklist.

2 Summary of the development process of the ENLIGHT checklist and its accompanying E&E document

A four-step modified Delphi consensus process was used to develop the ENLIGHT checklist, as reported by Spitschan et al. (2023), in accordance with the EQUATOR toolkit for developing reporting guidelines (https://www.equator-network.org/). The consensus process was initiated and coordinated by a steering committee consisting of researchers with expertise in the ipRGC-influenced responses. The protocol of the consensus process was pre-registered on the Open Science Framework (https://doi.org/10.17605/OSF.IO/XR965) and was approved by the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (MS IDREC) (approval number R78618/RE001). There were no deviations from the pre-registered protocol. The thinking-aloud sessions and written feedback, which took place after provisional finalization

[1] Spitschan, M., Kervezee, L., Lok, R., McGlashan, E., Najjar, R.P.

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of the checklist, were not part of the pre-registration. Briefly, the development of the checklist consisted of the following steps:

- **Literature review:** The steering committee identified (1) a preliminary list of reporting items and (2) participants with a track record in the field of ipRGC-influenced responses. This step resulted in an initial set of 61 reporting items, covering protocol, experimental, measurement, instrument and source-level characteristics as well as spectral, photometric, colour, spatial and temporal aspects of the light source. In addition, 115 participants were identified based on their track record in the field and invited to participate in the consensus process.
- **Consensus process – Round 1:** A total of 65 participants provided digital informed consent and completed the first online survey. Participants were asked to rate the importance of each of the 61 reporting items on a scale from 1 (very unimportant) to 7 (very important), or to indicate they did not know or recognize the item in an online survey. Using a pre-defined consensus threshold of 75 %, this process resulted in 24 items meeting the threshold for definite inclusion in the checklist. The remaining 37 items did not reach consensus and were therefore retained for discussion in the next rounds. Participants were also given the option to propose new items that were missing from the list of items and provide open feedback. Based on this round, a draft checklist containing 29 items was created by the ENLIGHT steering committee and circulated to the participants in the next round.
- **Consensus process – Round 2:** Using an online survey, participants were asked to indicate whether they felt any items were missing in the draft checklist that should have been included and whether they felt any items in the draft should not have been included. In addition, consensus was sought on items that were included in the draft checklist but had not been in the initial list. 63 participants completed this round. A consensus was reached on all 29 items in the survey.
- **Consensus process – Round 3:** Participants were invited to join semi-structured group discussions involving 4 to 11 participants led by at least two members of the steering committee. The goal of these sessions was to clarify any questions or concerns and to discuss the scope of the checklist and accompanying E&E document as well as the dissemination strategy. Recurring comments were distilled from the meeting minutes, which were used to further condense and improve the checklist. This resulted in a checklist consisting of 25 reporting items.
- **Consensus process – Round 4:** Participants completed an online survey to reach consensus on which items on the checklist are deemed mandatory to report regardless of the context of the experiment. In addition, satisfaction with the consensus processes was evaluated. Nine items reached consensus on being mandatory, and minor textual changes were made to the checklist. The majority (> 92 %) of participants reported being either satisfied or very satisfied with the consensus process, the final checklist and accompanying E&E document.
- **Independent pilot testing phase:** The checklist and E&E document resulting from the consensus process were evaluated by another group of experts that had not been part of the consensus process as a further level of validation. Oral and written feedback from these experts on the usability of the checklist and E&E document was used to refine these documents and prepare the final release version.

3 ENLIGHT checklist

Table 1 shows a list of items included in the ENLIGHT checklist. The checklist is split into two broad domains: study characteristics and light characteristics, within which there are items that may be included in the description of studies on the ipRGC-influenced responses to light. The ENLIGHT checklist adapted from (Spitschan et al. 2023) is shown in Table 1. A fillable PDF-version of the checklist is available at https://github.com/ENLIGHT-Project/ENLIGHT-Checklist/blob/06ee653046cffe833753028c2b4bc71cdb6a711b/1.0.2/ENLIGHT_Checklist_Release_1.0.2_20231016.pdf. The most updated version of the E&E document can be found at https://github.com/ENLIGHT-Project/ENLIGHT-Checklist/blob/06ee653046cffe833753028c2b4bc71cdb6a711b/1.0.2/ENLIGHT_E%26E_Release_1.0.2_20231016.pdf .[1]

[1] A link to the ENLIGHT checklist is also available on the website of the Equator Network

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Table 1 – ENLIGHT checklist adapted from (Spitschan et al. 2023)

Item	Description
A. Study characteristics	
A.1. Protocol-level characteristics	
Description of experimental setting [a]	Describe the experimental setting (e.g. room geometry).
Timeline of experiment (including timing and duration of light) [a]	Provide an overview of the timing of key study events, including timing and duration of light exposure.
Pre-laboratory sleep-wake/rest-activity behaviour	Describe the pre-laboratory sleep-wake or rest-activity behaviour (e.g. any measurement of participants' sleep-wake or rest-activity behaviour prior to entering the laboratory).
Pre-laboratory light exposure	Describe the pre-laboratory light exposure, including whether participants were given any instructions related to light exposure.
Immediate prior light exposure (in laboratory)	Describe the in-laboratory light conditions immediately prior to the experimental light exposure.
A.2. Measurement-level characteristics	
Measurement plane (e.g. horizontal or vertical) [a]	Describe the plane in which light measurement(s) were performed.
Measurement viewpoint and location [a]	Describe the location and direction at which the light sensor was placed during light measurements.
Type, make and manufacturer of the measurement instrument [a]	Describe the instrument being used to take each light measurement, including the manufacturer, type, make and model of the device.
Calibration status of the instrument	Describe the calibration status of the light sensor that was used to take each light measurement.
A.3. Participant-level characteristics	
Ocular health and functioning [a]	Provide any details on health and functioning of the participants' eyes.
Pupil size and/or dilation	Describe any pupil size measurements and/or whether pupils were pharmacologically dilated during the experimental protocol.
Relative time (e.g. to circadian phase or sleep)	Describe the time of the experimental light exposure relative to the participants' sleep or circadian timing.
B. Light characteristics	
B.1. Light sources	
Light source type(s) [a]	Tick all relevant boxes to indicate the type(s) of background and experimental light sources used in the study.
Type, make and manufacturer of the light source [a]	Describe the type, make and manufacturer of the light source(s) used in the study.
Use of wearable filtering apparatus (e.g. blue-blocking glasses)	Describe any wearable device(s) that modifies the absolute flux level or relative spectral distribution, or both, of light passing through it.
B.2. Light level characteristics	
Illuminance (lx) and/or luminance (cd/m^2) [a, b]	Provide the illuminance and/or luminance of the experimental light condition(s) used in the study.
Spectral irradiance and/or radiance distribution [b]	Provide the spectral irradiance and/or radiance distribution of the experimental light condition(s) used in the study.
α-opic irradiance and/or radiance (including melanopic) [b]	Provide the α-opic irradiance and/or radiance of the experimental light condition(s) used in the study.

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α-opic equivalent daylight illuminance and/or luminance (EDI/EDL, including melanopic) [b]	Provide the α-opic equivalent daylight illuminance and/or luminance of the experimental light condition(s) used in the study.
B.3. Colour characteristics	
Peak wavelength and bandwidth	Provide the peak wavelength and bandwidth of the experimental light condition(s). Note that these metrics are most relevant for monochromatic or narrowband light sources.
Colour appearance quantities (any)	Provide colour appearance quantities of the experimental light condition(s), such as any metric describing position in a chromaticity diagram or colour space, or correlated colour temperature (CCT), symbol T_{cp}.
Colour rendering metrics (any)	Provide any colour rendering metrics, such as the Colour Fidelity Index (CFI), symbol R_f.
B.4. Temporal and spatial characteristics	
Location of stimulus and viewing distance [a]	Describe the location of the light stimulus relative to the participant and/or the relative distance between the light stimulus and the participant, and direct or indirect viewing condition.
Temporal pattern (including flash frequency and waveform)	Describe the temporal pattern of the light sequence (e.g. the flash frequency or inter-stimulus interval) and the waveform (e.g. square, sinusoidal).
Relative or absolute size of the stimulus	Describe the size of the light stimulus, either absolute or relative (in relation to the visual field).

[a] Item reached consensus for being essential to report in any study regardless of experimental context.
[b] Luminance and radiance metrics (as opposed to illuminance and irradiance) are mainly relevant for emissive surfaces.

4 Utilization of the ENLIGHT checklist and its accompanying E&E document

Who should use it?

The ENLIGHT checklist is designed to be used primarily by scientists/authors using light as an in-laboratory intervention in humans as a guide to report light metrics and related protocol characteristics in their manuscripts, grant applications or other reports. The use of the checklist alongside published works would enable scientists or authors who wish to perform systematic reviews or meta-analyses on the impact of light on ipRGC-influenced responses to more easily locate and synthesize details of the lighting interventions reported in studies. By providing a guided reporting practice, the checklist will enable researchers to draw more robust conclusions about the interactions between light and human health, further advancing our understanding of this important area of study. The checklist would also allow editors, reviewers and readers of scientific journals to better appraise the completeness of reporting related to studies on the ipRGC-influenced effects of light. However, it should be emphasized that the purpose of the checklist is predominantly to enable consistent and documented reporting, rather than to evaluate the quality of a study. Suitable reporting practices in lighting research will benefit not only the scientific community, but also light engineers, architects and the lighting industry, enabling them to translate scientific findings more accurately into the development of data-driven environmental lighting and light-therapy devices.

What should the checklist be used for?

The ENLIGHT checklist is intended to be used when reporting or describing studies at either the stage of design and proposal (e.g. grant applications) or at publication / dissemination. The checklist should be used as an addition to any other relevant reporting checklist (based on study design or population, e.g. *CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials* (Schulz et al. 2010)), and is intended to assist authors in reporting their protocol to enable reproducibility and enhance external validity. The accompanying E&E document is specifically designed to aid authors in the completion of the

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checklist by providing descriptions of each item and giving instructions of what is expected. The checklist and the E&E document are not intended to instruct authors on how to conduct different measurements, or how to design and conduct research studies, nor are they intended to evaluate the quality of a study. It should be noted that some of the metrics included in the checklist can be calculated from others. However, authors are encouraged to provide the most comprehensive description possible of their experimental lighting conditions, rather than relying on readers to calculate metrics independently. Additional resources to assist authors in calculating and describing metrics are provided in the E&E document.

How should it be used?

When completing the checklist, authors must indicate the page, figure and/or table where the information for each item can be found in the manuscript (or other document being reported on). If an item is either not available (the item or metric was not collected or measured), or not applicable (not relevant to the study or proposal in question), the relevant box can be selected. Those using the checklist should take note of items which have been deemed as essential by the experts involved in the consensus process. For these items, it is not possible to indicate “not applicable” as they have been deemed as relevant regardless of the context during the consensus process that led to the production of the checklist. Authors can however still indicate if an item is not available to report. If additional clarification is needed regarding an item, the E&E document can be consulted. Lastly, given that the checklist is not intended to prescribe a particular methodology or control, authors should respond to each item with where in the manuscript or document that item is described, not whether a particular element or control was present. For example, authors can simply state in the manuscript that pre-laboratory sleep-wake patterns were not controlled, and participants were allowed to adopt their usual sleep-wake schedule prior to entering the laboratory. On the checklist, the authors would indicate where this is stated/described in the manuscript.

5 Associations and alignment with existing CIE documents

Multiple CIE documents have been utilized throughout the development of the ENLIGHT checklist and E&E document, and have been referenced in the reporting accordingly. For example, the terminology in the ENLIGHT checklist and E&E document were adopted from the International Lighting Vocabulary (ILV), published in CIE S 017/E:2020 (CIE 2020b), which provides definitions, symbols and units of commonly used terms and metrics related to lighting.

This document complements the ENLIGHT checklist and E&E document, whereby it further refers readers to specific CIE documents for the measurements and reporting of specific lighting stimuli used in laboratory settings. For instance, for the specific measurement and reporting of protocols pertaining to the periodic waveform and light modulations in laboratory setting, it is recommended to consult CIE TN 012:2021 *Guidance on the Measurement of Temporal Light Modulation of Light Sources and Lighting Systems* (CIE 2021); for studies involving photometric quantities in different lighting conditions (i.e. scotopic, mesopic, photopic), CIE TN 004:2016 *The Use of Terms and Units in Photometry – Implementation of the CIE System for Mesopic Photometry* (CIE 2016) can be consulted.

The document CIE 213:2014 *Guide to Protocols for Describing Lighting* (CIE 2014) provides a catalogue of descriptors for lighting solutions and their aspects for practical applications. These descriptors exist in two different complexities: simple descriptors common to any lighting solution and specialized descriptors tailored to specific applications. This document complements the existing framework by focusing specifically on describing and reporting interventional studies independent of implementation.

The document CIE TN 011:2020 *What to document and report in studies of ipRGC-influenced responses to light* (CIE 2020a) provides a concise overview of factors that may be important to report and commonly are reported in studies of the ipRGC-influenced responses to light. The document covers suggested aspects of the project, stimulus, outcomes and statistical analyses, which can be reported in manuscripts or conference publications. This document, incorporating

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the ENLIGHT checklist, complements this work by describing an actionable tool for documenting studies of the ipRGC-influenced effects of light.

The document CIE S 026:2018 *System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light* (CIE 2018) is the international standard on metrics for describing the ability of visible optical radiation to stimulate the five photoreceptors in the human eye and contribute to the ipRGC-influenced responses to light. The ENLIGHT checklist and E&E document can be used in conjunction with CIE S 026 and would directly promote the utilization of the accompanying alpha-opic toolbox and user guide whenever α-opic irradiance and/or radiance and α-opic EDI and EDL are required.

It is important to highlight that the ENLIGHT checklist and E&E document could benefit from a more comprehensive section dedicated to describing the human visual field of view (FOV). Changes in the FOV are a critical factor that should not be overlooked when quantifying spectral variations and characterizing retinal exposure. Readers and researchers are strongly encouraged to consult the document *Retinal Exposure Assessment – Horizontal or Vertical Alpha Irradiance or Illuminance?* (Sliney 2019) for a detailed exploration of the impact of FOV on retinal exposure.

6 Impact and benefits of this document and the ENLIGHT checklist

Technological benefit: This document, incorporating the ENLIGHT checklist, will not only help reviewers, editors and readers assess the completeness, applicability and potential confounds of study findings, but will also enable lighting engineers, architects and the lighting industry to accurately translate scientific discoveries into the development of innovative and data-driven environmental lighting and light-therapy devices. By establishing a uniform reporting practice, the ENLIGHT checklist will promote robust and reproducible research, facilitate comparisons between studies and advance the field of lighting research. In addition to improving the translation of scientific findings into the development of innovative lighting technologies, this document, incorporating the ENLIGHT checklist, will also facilitate more accurate meta-analyses and systematic reviews of ipRGC-influenced responses to light in humans. By providing a guided reporting practice, these tools will enable researchers to draw more robust conclusions about the interactions between light and human health, further advancing our understanding of this important area of study.

Societal benefits: This document, incorporating the ENLIGHT checklist, establishes a basis for systematic and uniform reporting practices for light-based interventions, leading to a more comprehensive understanding of the impact of light on human physiology and health. This will, in turn, promote the development of data-driven active and passive light interventions for a variety of health conditions, including chronobiological disorders, mood disorders, myopia and more. By improving the accuracy and reliability of research findings, this approach will help ensure that light-based interventions are effective, safe and accessible to all who need them. Ultimately, this will contribute to the improvement of public health and the well-being of individuals and society.

Environmental benefits: By establishing proper reporting practices for light metrics in scientific publications, this document, incorporating the ENLIGHT checklist, will (1) improve the evaluation of research and increase the reproducibility of science; (2) lead to a more refined understanding of the impact of environmental light on human health and (3) facilitate the development of efficient, cost-effective and environmentally sustainable light therapy strategies. These benefits align with several United Nations Sustainable Development Goals (SDGs) (see https://sdgs.un.org/goals), including good health and well-being (SDG 3), industry, innovation and infrastructure (SDG 9), sustainable cities and communities (SDG 11) and life on land (SDG 15). By promoting responsible and sustainable use of lighting technologies, this approach will contribute to a healthier and more sustainable future.

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