DOI: 10.25039/TN.011.2020

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

TECHNICAL NOTE

What to document and report in studies of ipRGC-influenced responses to light

CIE TN 011:2020

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Any mention of organizations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of any lists, up to the time of going to press, these may not be comprehensive.

This Technical Note is the product of DR 3-34 “Documentation template for studies on non-image-forming effects”. The Division Reportership comes under Division 3 "Interior Environment and Lighting Design". The authors of this Technical Note are:

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Summary

Interest in studying the ipRGC[1]-influenced responses to light is strong, and continues to increase. The research teams who work in this domain come from many disciplines, each with their own research perspectives. Perhaps as a consequence, reviewers and readers of papers in this field are often frustrated by missing details in the reports, particularly in relation to the stimulus conditions – the light conditions to which people and animals are exposed. This impedes attempts to conduct systematic reviews that link stimulus and response and slows progress towards recommendations and standards. This document provides a concise template for reporting investigations of ipRGC-influenced responses to provide guidance to research teams from all fields. It builds upon the guidance for describing stimulus conditions described in publication CIE 213:2014 *Guide to Protocols for Describing Lighting*, but is specifically tailored for research in this aspect of applied lighting and for applying the CIE system of metrology for ipRGC-influenced responses to light described in CIE S 026:2018. The CIE makes this document freely available to encourage researchers, journal reviewers, and journal editors to follow this guidance, with the aim of enhancing the usefulness of this research for knowledge mobilization and application.

1 Introduction

The number of studies on effects of light exposure influenced by ipRGCs has substantially increased in the last decade. This is not surprising, as it is an exciting research topic and there are many gaps in our understanding (CIE 2016). The topic is complex, involving many variables influencing various physiological and psychological processes. The variables are environmental-, stimulus- and person-related. Environmental variables include date and time of day of measurements, location of study, setting, qualitative description of room surfaces, and other conditions such as air temperature and pressure. Stimulus variables include light intensity, spectral properties, timing and duration of exposure, and possibly the retinal irradiance pattern. Person variables include visual capabilities, chronotype, age, photosensitivity and light history. Furthermore, the effects of light exposure on people can be assessed by means of questionnaires, tests, tasks, behavioural observations, and physiological measures. Careful research design, and sometimes other dependent measures, are also needed to differentiate ipRGC-influenced responses from other parallel processes.

The research teams who work in this domain come from many disciplines, each with their own research perspectives. Perhaps as a consequence, reviewers and readers of papers in this field are often frustrated by missing details in the reports, particularly in relation to the stimulus conditions. This impedes attempts to conduct systematic reviews that link stimulus and response and slows progress towards recommendations and standards.

A concise template or protocol for reporting investigations of ipRGC-influenced responses to light (IIL responses, as specified in CIE S 026 (CIE 2018)) would provide guidance to research teams from all fields about how to report their investigations in such a way as to enhance their usefulness for knowledge mobilization and application. This template builds upon the guidance for describing stimulus conditions described in publication CIE 213:2014 *Guide to Protocols for Describing Lighting* (CIE 2014), but is specifically tailored for research in this aspect of applied lighting, and upon the recommendations for reporting light exposures in CIE TN 003:2015 *Report on the First International Workshop on Circadian and Neurophysiological Photometry* (CIE 2015) and in CIE S 026:2018 *CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light* (CIE 2018). The focus here is on interior applications, for which detailed guidance is provided; nonetheless, the general approach might also apply to light exposures occurring outdoors. Other documents that provide guidance for researchers in this field are the articles by Price et al. (2019) (providing general, high-level guidance aimed particularly at occupational health research), and Spitschan et al. (2019) (providing measurement guidance for accurate assessment of light exposures).

This Technical Note distinguishes between ‘documentation’, with the purpose of recording details of the research for future use and comprehensive archival records, and ‘reporting’, referring to the presentation of the research in a journal or a conference paper. This is reflected

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1 ipRGC: intrinsically photosensitive retinal ganglion cell

in the structure of the Technical Note. The requirements for full documentation of research related to IIL responses are contained in Clause 3, and the requirements for journal reporting are summarized in a template (Clause 4).

By using this Technical Note as a guideline for documentation, researchers will:

- support replication to strengthen validity;
- facilitate cross-experimental conclusions; and
- allow detailed analysis of data in the future.

Journal editors and reviewers will expand the value of studies on IIL responses and will speed progress towards practical applications by applying the reporting recommendations outlined in the template.

The Technical Note was designed primarily to apply to research involving humans, although some elements might also apply to research involving animals.

2 Consistency in language

Achieving clarity of communication about both the stimulus and the responses is challenging when many scientific disciplines come together, each with their own vocabulary. Each writer, coming from a particular perspective, should be aware that the work could be of interest to scientists and practitioners from other backgrounds, and consider paying close attention to the definitions of key terms. Clarity will be enhanced when authors cite established glossaries or vocabularies that provide definitions of key terms. Consistent use of language will facilitate faster scientific advancement.

For lighting terminology, the established source is the International Lighting Vocabulary, CIE S 017 (CIE -[1]). Two terms that are frequently used incorrectly are “artificial lighting” and “natural lighting”. These terms have been deprecated and replaced by “electric lighting” and “daylighting”, respectively.

New terms relating to ipRGC-influenced responses to light are defined in CIE S 026 (CIE 2018). SI units should be used in the representation of quantities.

For photobiology there is no single consensus document that establishes definitions of terms related to human responses, but sources include (Braslavsky 2007) for photochemistry terms, and (Wright et al. 2009) for circadian rhythms.

In psychology and the behavioural sciences, the American Psychological Association (APA) Dictionary of Psychology (VandenBos 2015) is widely accepted.

3 What to document

Most research in the domain of ipRGC-influenced responses to light seeks to establish a causal relationship – or at least a strong correlation, excluding likely confounding variables. This report and the template may be used for both laboratory and field investigations. Where there is less experimental control, there may be limitations in the breadth of information reported; these should be explained and justified. Reduced experimental control, as in the case of field investigations and exploratory work, can benefit from the inclusion of additional measurement of potential confounding variables.

The requirements for documentation are more substantial than those required for a journal or conference report. This ensures that researchers have collected and retained the information necessary to answer requests for follow-up information from journal reviewers and editors, and information required to support later re-analyses. If researchers intend to post research data on an open-source platform, then full documentation and metadata should be posted with the data set. The choice and level of detail for documentation depends to a large extent on the topic and research questions. For specific IIL-research-related requirements, this Technical Note

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1 2nd Edition of CIE S 017 under preparation. Stage at the time of publication: CIE FDIS 017:2019, approved and in preparation for publication.

includes examples in references to papers in which representative descriptions are included. To facilitate cross-experimental conclusions, this document includes references to commonly used questionnaires and measures for IIL research (see 3.1.1 and 3.3).

3.1 Experimental set-up and participants

The information in this subclause addresses the specification of control variables – those that were intentionally limited in their variation, or which were measured in order to assess the external validity of the work (Veitch et al. 2019).

3.1.1 Participants

To describe the population used in the experiment, report in a publication (not only document in project files) at least:

- number of participants,
- age,
- sex,
- visual characteristics (e.g. corrective lens use; colour vision capabilities).

Some studies will require specialized descriptors. The reporting of specialized descriptors will depend on the specific focus of the investigation, but consideration should be given to documenting the following in IIL-related research:

- light history:
  - derived from:
    a. a questionnaire, e.g. Harvard Light Exposure Assessment (H-LEA) (Bajaj et al. 2011), or
    b. daily logs, as in (Hébert et al. 2002), or
    c. light dosimeter measurements of participants in their daily lives, as in (Hubalek et al. 2006), or
  - number of days in laboratory before experiment with description of lighting condition as described in 3.2.2 ("Light exposure") (examples in (Smith et al. 2004) and (Chang et al. 2011)).

  The majority of studies that investigated the impact of light history on IIL responses record three to seven days of light history.
- skin colour and eye colour, both of which affect responses to light exposure (Harley and Sliney 2018; Yang et al. 2009)
- the material characteristics of corrective lenses (e.g. use of spectral filters)
- chronotype (questionnaire examples: Morningness-Eveningness Questionnaire (MEQ) (Horne and Östberg 1976) or Munich ChronoType Questionnaire (MCTQ) (Roenneberg et al. 2003));
- photosensitivity (examples are: photosensitive epilepsy diagnosis; visual stress risk assessed with Pattern Glare Sensitivity (Wilkins and Evans 2012; Wilkins et al. 2016));
- stress symptoms (questionnaire example: Perceived Stress Scale (PSS) (Cohen et al. 1983));
- health (questionnaire example: 12-Item Short-Form Health Survey (SF12) (Ware et al. 1996));
- mental health (e.g. depression) (questionnaire example: Patient Health Questionnaire (PHQ9) (Kroenke et al. 2001));
- sleep quality and sleep-wake history (questionnaire example: Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989));
- recent consumption of common prescription and non-prescription psychoactive substances, including caffeine, alcohol, medications, tobacco, marijuana, etc.

3.1.2 Environment and context

Report the following to define the context of the investigation. For laboratory investigations, greater detail concerning the characteristics of the space will generally be feasible to both document and to report:

- date (or range of dates) and time of day of measurements;
- geographical location of study (latitude and longitude);
- setting (home, workplace, outdoors);
- qualitative description of room surfaces, including their colours, finishes, and specularity;
- environmental conditions such as air temperature;
- participant variables such as clothing and activity (ISO 2005, ASHRAE 2013).

CIE 213:2014 (CIE 2014), subclause 4.2 provides a comprehensive list of optional environmental and context-related information to be documented. Here, we consider the following to be a required minimum list of information to document:

- photographs of the space from multiple vantage points;
- specification of surface finishes and colours for walls, ceiling, floor, window treatments and major furnishings, if possible spectral reflectance of the surfaces;
- drawings showing plan and elevation, including room dimensions and orientation, the position and size of the luminaires, windows and daylighting systems, the position of the observer.

It is desirable, although not always feasible, to document environmental parameters beyond lighting that are known to influence underlying processes which are of interest in investigations of IIL responses. These include measurements of ventilation operation, which affects alertness (e.g. CO_2 and other pollutant concentrations; air movement) (ASHRAE 2019), the thermal environment, which affects comfort (radiant temperature and relative humidity) (ASHRAE 2013, ISO 2005), and the acoustic conditions, which affect arousal and cognitive performance (e.g. sound levels).

3.1.3 Lighting

To report the relevant lighting components, include information with respect to the electric lighting and daylighting of the space:

- electric lighting systems and components: pictures or drawings and description of lamps, luminaires and control systems and their locations, spectral power distribution (SPD), colour rendering properties, correlated colour temperature (CCT), chromaticity coordinates of the lighting as experienced, direction of illumination (at least qualitatively, although quantitative information, e.g. luminous intensity distribution, is preferred), temporal light modulation;
- daylight provision: drawings and description of windows, optical properties of windows, window view and orientation, daylighting systems (including shading), prevalent weather or sky condition.

Optional lighting-related information to be documented is comprehensively listed in CIE 213:2014 (CIE 2014), subclause 4.3. Consider at a minimum:

- drawings, photographs and sections including all measurement locations (where possible tag them with measurements of luminance or illuminance at the selected location, for each scenario);
- documentation of exterior conditions at the time of the experiment (measurements, weather files, pictures or diary).

3.2 Light stimulus

For most lighting research this is the principal focus of the investigation, and its reporting and documentation is of greatest importance to the reader (Veitch et al. 2019, Knoop et al. 2019). This rests on the foundation of the CIE system of physical photometry (ISO/CIE 2005) and the metrology of optical radiation for IIL responses (CIE S 026). See also CIE 213:2014 for details concerning measurements for describing lighting installations.

3.2.1 General considerations

For all of the following clauses, it is critical that the researchers document the following:

- the instruments used, their specifications, and their calibration status;

  NOTE Considerations with respect to performance characterization, calibration and deployment of dosimeters can be found in (Price et al. 2012), (Figueiro et al. 2013) and (Markvart et al. 2015).

- the measurement grid, location, time, and direction of measurements.

3.2.2 Light exposure

For laboratory experiments, it is essential to measure the light exposure using either a device that reports spectral measurements (preferred) or one that incorporates international standard action spectra as built-in functions, and report:

- all five relevant α-opic quantities as described in CIE S 026, as measured at the eye level of the participant on a (usually vertical) plane perpendicular to the direction of view (examples in Brainard et al. 2015, Dauchy et al. 2016);
- illuminance at identified locations (e.g. meaningful locations for the lighting application, both horizontal and vertical), for comparison to the established literature and application documents; and
- the spectral power distribution measured at the eye level of the participant on a (usually vertical) plane perpendicular to the direction of view, or the spectral power distribution of the acute stimulus and the background light environment from the observer's point of view (Spitschan et al. 2019).

The quantities described in CIE S 026 may be calculated using the CIE S 026 Toolbox (CIE 2020), available for download from the CIE website. Quantities and field-of-view aspects described in CIE S 026 may also be reported in addition to those listed above, if they are of interest for the specific application.

Spitschan et al. (2019) suggested documenting the measured or estimated percentage of eye opening to obtain insight into retinal illuminances.

For field investigations, the ideal is to measure and report the light exposures at the eye level in a (usually vertical) plane perpendicular to the field of view of the participant, and to do so in the same manner as for laboratory experiments at a frequency that does not disrupt the participants but is adequate to capture changing daylight conditions, where these occur. This level of detail is not always practical. It is in any case necessary to follow the general considerations above and also to document the spectral characteristics of the measurement device if it is not a conventional spectral measurement device. Light exposures should be reported as irradiances (or radiances) per sensor channel (e.g. if there are three detectors, report exposures on each separately). Reporting light exposures only in photopic quantities is not acceptable.

3.2.3 Spatial distribution

The luminance distribution of a scene might affect IIL responses (e.g. Glickman et al. 2003, Lasko et al. 1999, Rüger et al. 2005, Visser et al. 1999), therefore it is necessary to report:

- a qualitative description of the luminance distribution from the observer's viewpoint by means of a photograph of the experimental set-up (in a laboratory), or (where feasible) photographs of key views of a field setting.

Optional information to be documented with respect to the spatial distribution is comprehensively listed in CIE 213:2014, subclause 4.4.2.1., 4.4.2.2., 4.7.2.1. Consider at a minimum:

- luminance spot measurements in a grid of measurement points and measurement of areas of which the luminance is substantially greater than the average or adaptation luminance from the observer's viewpoint (cf. Fig. 29, Fig. 30 in CIE 213:2014). Mark these areas on photos, plans or sections and tag them with the measurements.

Specialized descriptors to account for spatial and/or temporal variation spectrally, as well as spatially and/or temporally resolved irradiance measured at the eye level of the participant on a (usually vertical) plane perpendicular to the direction of view can be considered for documentation. The appropriate measuring approach depends on the experimental set-up (Knoop et al. 2019); suggestions for measuring approaches are for example:

- luminance picture and measurement with a spectroradiometer from the observer's viewpoint, or
- a spatially-resolved spectral scan from the observer's viewpoint (e.g. Jung and Inanici 2019, Knoop et al. 2019).

Gaze plots and heat maps of eye tracking devices can be included, when an enforced or encouraged view direction fixation is not given.

Field investigations present a special problem. In a field intervention study (e.g. in a fixed location), confidentiality concerns might preclude the taking of photographs. In such a case, the reporting of verbal descriptions supplemented with luminance spot measurements will provide useful information to the reader. When individuals' light exposure patterns are tracked in a naturalistic or ecological way, it might not be practical to obtain any form of information about luminance distributions. In this case, researchers might collect qualitative descriptions of the places where participants spend their time, and consider using these to aid in the interpretation of the light exposure measurements.

3.2.4 Timing, duration, and pattern

Research indicates that timing, duration, and daily pattern of light exposure might affect IIL responses (e.g. Khalsa et al. 2003, Chellappa et al. 2011, Chang et al. 2012, St Hilaire et al. 2012, Vandewalle et al. 2013, Rüger et al. 2013). The duration of light exposure should be long enough for the intended process to operate, therefore it is necessary to report:

- the timeline of the experiment explained in detail, in clock time;
- the duration of exposure in minutes or hours;
- the sequence of exposures, including pre-experimental light and environmental exposures to the greatest degree of detail possible.

Optionally, the study might require specialized descriptors. These are comprehensively listed in CIE 213:2014, subclause 4.10.2.2.

3.3 Dependent measures

The range of possible dependent measures for studies of ipRGC-influenced responses to light encompasses the full range of physiological, behavioural and psychological outcomes. Regardless of which suite of measures is the focus of the investigation, it is essential to report:

- what was measured and how it was scored;
- literature references that confirm validity and reliability of measure for the suggested IIL response(s), the time scale of the exposure, learning effects / curves and fatigue on the task.

The following list gives a sample of the possible range of dependent measures that might be included in such investigations, but the selection for any given investigation is left to the creativity and resources of the research team:

- electro-encephalograph (EEG) readings (e.g. Cajochen et al. 2000, Lockley et al. 2006, Vandewalle et al. 2018);
- eye movements and pupil size (e.g. Kahneman et al. 1968)
- subjective sleepiness (Shahid et al. 2012), e.g. the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg 1990), or the Toronto scale (Shapiro et al., 2006);

- hormone secretion (see (Cohen et al. 1997) for methodological guidance) (e.g. Cajochen et al. 2000, Lockley et al. 2006);
- phase shift: dim light melatonin onset (e.g. Lewy et al. 1999, Martin and Eastman 2002);
- sleep onset and duration, for example by using wrist actigraphy with a dedicated device or with a smartphone app (e.g. Fino and Mazzetti 2019, Sadeh 2011);
- cognitive performance measures of constructs such as attention, vigilance (e.g. psychomotor reaction time (Dinges and Powell 1985)), memory, cognitive workload (e.g. cognitive interference (Stroop, 1935)), overall processing capacity (e.g. digit substitution (van der Elst et al. 2006)) or comprehension.

3.4 Statistical analysis

To increase the value of studies conducted, accurate and appropriate reporting of the statistical analysis is required. In addition to the sample size and the statistical tests, the assumptions of the statistical tests as well as effect sizes need to be reported (Uttley 2019). This includes decisions made with respect to retained or excluded cases, and decisions about scoring of the measures.

4 What to report in a journal or conference publication

PROJECT DETAILS
People (see CIE 213:2014, Subclause 4.1.2.1, including examples) ***Who are the people who took part in the experiment?***
number of participants, age, sex, general ophthalmic health status, including colour vision status, specify the wearing (or not) of spectacles or contact lenses, material and treatment of spectacles or contact lenses.
Project-specific specialized descriptors: chronotype, light history, sensitive individuals
Context (see CIE 213:2014, Subclause 4.2, examples in 4.2.3) ***What are the characteristics of the space used in the experiment?***
date and time of day of measurements or exposures, setting, geographical location
photographs from the participants viewpoints (fish-eye are preferred), verbal or quantitative specifications (e.g. room dimensions) where required
parameters related to the indoor environment such as air temperature
participant characteristics such as clothing and activity
Lighting (see CIE 213:2014, Subclause 4.3, examples in 4.3.3) ***What provides light to the space?***
specify electric lighting: pictures or drawings and description of lamps, luminaires and control systems, SPD, colour rendering properties, CCT, chromaticity coordinates of the lighting, direction of illumination, temporal light modulation
specify daylight provision: drawings and description of windows, window view and orientation, daylighting systems, prevalent weather or sky condition
STIMULUS (INDEPENDENT, DEPENDENT OR CONTROL VARIABLE)
General considerations
specify measuring equipment and measurement details: manufacturer, model, serial number and calibration status of measuring equipment, measurement grid, location, and direction of measurements
use SI units and definitions from accepted vocabularies and CIE publications where these exist
Light exposure
five α-opic quantities (e.g. α-opic irradiance or α-opic equivalent daylight (D65) illuminance (α-opic EDI)) at eye level on a (usually vertical) plane perpendicular to the direction of view for laboratory setting; five average α-opic quantities (e.g. α-opic irradiance or α-opic EDI at eye level on a (usually vertical) plane perpendicular to the direction of view in field studies
the spectral irradiances (or radiances, as appropriate to the investigation) always for laboratory investigations, and for field studies when possible
illuminance at identified locations, for comparison to the established literature and application documents
luminance distribution from the observer's viewpoint
Duration (including temporal variability, see CIE 213:2014, Subclauses 4.10.2.1 and 4.10.2.2)
timeline of experiment, including overall duration of the experiment, timing of light exposure (in clock time), dim light exposure, duration of the light exposure (in min or h), duration of dim up and dim down (in min), and pattern.
MEASURE (DEPENDENT VARIABLE)
specify what was measured and how it was scored, demonstrate validity and reliability
STATISTICAL ANALYSIS
sample size, effect size, descriptive statistics (means, standard deviations, medians, maximum, minimum) for all measures, statistical tests, decisions and assumptions

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