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

ABSTRACT BOOKLET

of

CIE Expert Workshop on Research Methods for Human Factors in Lighting

August 13–14, 2018

Aalborg University Copenhagen, Copenhagen, Denmark

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Non Image Forming Effects, Perception and Vision

INTEGRATION OF NON-IMAGE FORMING EFFECTS OF LIGHT IN CONTROL SYSTEMS FOR VENETIAN BLINDS AND ELECTRIC LIGHTING

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Abstract

1. Motivation, specific objective

Light has an impact not only on our visual comfort and visual capabilities, but also on our behaviour and physiology: it is shown that exposure to light can directly boost alertness, cognitive performance, and improve mood. These non-visual effects of light are also called “Non-Image Forming” (NIF) effects. NIF effects of light are currently not sufficiently considered in lighting of indoor work environments due to the lack of knowledge and proper technology. However, taking those effects into account in the design of dynamic lighting systems is important to improve health and productivity of the users. Nowadays, people spend the majority of their time inside of buildings, where they very likely receive an insufficient amount of light during daytime and too much light in the evening, and this inappropriate light exposure can likely lead to circadian rhythm misalignment. For office workers, this may result in poor task performance. At the same time, visual comfort of the occupants and energy saving are very important factors to be considered in lighting for buildings.

The objective of this study is to investigate the biological effects of a dynamic control of daylight and artificial lighting on humans. The smart controller for venetian blinds and artificial lighting is aimed to optimize NIF effects of light such as alertness and cognitive performance of occupants, while preserving visual comfort and low electrical energy consumption. In our field study we are going to evaluate the impact of different lighting conditions in offices on the circadian system and on visual comfort in healthy subjects over several days. The aim is to show that an optimal dynamic lighting control integrating both natural and artificial light has beneficial effects on the human physiology and psychology, with respect to a conventional control system.

2. Methods

The study is carried out in two identical office rooms in the LESO solar experimental building in EPFL. The rooms are south-oriented and occupied by a single user. An advanced controller for venetian blinds and electric lighting designed to simulate outdoor light patterns, i.e. to follow the daylight course throughout the day in terms of lighting levels, is implemented in the first office (*test room*). In the second office (*reference room*), a controller designed to keep static lighting conditions for only visual requirements is applied. The lighting parameters assessment is performed by High Dynamic Range vision sensors placed close to the workstations and on the ceiling. These sensors are able to continuously capture luminance maps, from which the useful parameters such as pupillary vertical illuminance, horizontal illuminance on work plane, and the glare index “Daylight Glare Probability” (DGP), are extracted. Thirty-four subjects are going to take part in the experiment in a cross-over-within-subjects design. Each subject is going to spend one week in the test room and one in the reference room, with at least 7 days of break between the two sessions. During the time spent in the offices, i.e. in the normal working hours, between 8h00 and 18h00 - subjects will carry out their normal work and regularly perform some cognitive tests and complete questionnaires throughout the day to evaluate their cognitive performance, alertness, mood and visual comfort. Moreover, saliva samples will be regularly taken for the assessment of their cortisol concentrations, and skin temperature in 5 different spots on the body will be continuously recorded by means of i-buttons, small sensors of the size of a coin. Lastly, their activity and sleep/wake patterns will be monitored by means of actigraphy watches that they will wear for the entire duration of the study.

3. Results

A preliminary experiment was performed in the two offices during 13 days in winter in order to assess the performance of the advanced controller for venetian blinds and electric lighting. The novel smart controller demonstrated its capabilities in terms of glare protection and daylight sufficiency, as both the

glare index and vertical illuminance were kept in the desired ranges. In addition, more variable vertical illuminance levels and high glare index values were registered in the reference room, indicating that the visual comfort would not be optimal for an occupant at this time of day/year. The planned field study involving human subjects will allow investigating the impact of the novel controller also on NIF functions.

4. Conclusions

This study will allow to investigate the effects of a dynamic office lighting control on humans' circadian system and visual comfort. Preliminary tests of the controller showed its effectiveness in keeping target indoor luminous conditions. The novel smart controller is expected to improve the alertness, cognitive performance and visual comfort of office users. At the same time, the energy consumption due to electric lighting in the test office is expected not to be considerably higher than the energy consumption in the reference scenario. The field study is going to show the effectiveness of the control system in pursuing the mentioned goals. The results of this study will bring new scientific and practical insights to building automation for personalized lighting at workspaces.

SPECTROMETRIC INSTRUMENTATION FOR IN SITU MONITORING OF SPECTRAL COMPONENTS IN DYNAMIC LIGHTING SCENARIOS

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Abstract

We present a spectrometric instrumentation to monitor and log the spectral characteristics of the light in hospital rooms over long term periods during a trial of the effect of controlled lighting on patients. Each room has been equipped with a dynamic lighting system enabling change of correlated colour temperature of the light over the day. The objective is to estimate and document the available light exposure to the patient including the daylight through the window. The calibrated spectral measurements allows for evaluating the stimulus intensities for all five photopigments in relation to both visual and non-visual effects of the light in the rooms.

1. Motivation, specific objective

There is a growing focus on daylight and artificial light in the fields of health and psychiatry as an element that can support conventional medical treatment. In this project daylight is combined with a LED based dynamic luminaires so there is a need for documentation of the light conditions during the interventions. The objective is to provide calibrated spectral irradiance measurements in the rooms to monitor and log the spectral characteristics of the light in the long term trials and to be able to quantify the difference in lighting conditions in a dynamically controlled and not controlled room. The calibrated spectral measurements allows for evaluating the stimulus for all five photopigments as recommended by CIE using the α-opic irradiances, i.e. cyanopic, chloropic, erythropic, melanopic and rhodopic irradiances measured in W/m^2.

The applied spectral sensors needs to be small and unobtrusive not to be disturbing in the hospital room, they further need to be sensitive to low light conditions and they need to be inexpensive. Normal spectrometers do not comply with these requirements and for this setup new types of spectral sensors have been investigated and chosen for the measurement system.

2. Methods

A spectral sensor of the so-called “Pancake” configuration is used for the measurements. It consists of a linearly variable filter on top of an array detector chip and allows for spectral measurements from 380 to 700 nm. The spectral resolution is around 5-9 nm. With USB connection the sensor weighs 15 g and has a size of 10x22x38 mm^3. It is a low cost sensor, less than one fifth of price of handheld spectrometers, allowing for inexpensive multipoint measurements.

The spectral sensor itself has a narrow acceptance angle and for the ambient light measurements a cosine response is required. Therefore, the sensors has been installed in small metal boxes with a hemispherical diffuser in front of the sensor array.

Prior to the installation at the hospital these sensor boxes has been calibrated for spectral irradiance in the photometric laboratory using a 1000 W FEL standard spectral irradiance lamp at a distance of 50 cm. Further the sensors has been characterised for dark noise and specta for the used integration times has been saved. Both dark correction and calibration is applied in the pc control program.

The control program has been developed to subsequently take measurements from all the installed spectral sensors and store the measured and calibrated spectral power distributions with a timestamp and serial number for the sensor. Prior to each measurement the program automatically finds the optimal integration time for the current light conditions, ensuring no saturation and a good signal level of more than 60 % of the saturation level. The possible integration times has been restricted to 72 from 10 μs to 10 s.

In each of four rooms, three sensors has been installed to monitor the light conditions. One sensor is placed at the top of the window on the end wall measuring the daylight entering the room. The two other sensors are placed on each side wall approximately 1.5 m from the end wall with the window and at a height of 1.5 m. The three sensors in a room are connected to a USB-Ethernet hub. The sensor boxes are painted white and no wires are visible, which is essential in the hospital ward. All twelve spectral sensors are connected to a pc via an Ethernet switch. The sensors are powered through the

The spectral data logging system runs with no internet access to comply with patient data regulation.

3. Results

The sensors has been installed and will be monitoring and logging spectral data in the four hospital rooms from April 2018 an onwards. Data will be collected and presented to show the effect of the different lighting conditions in the rooms, e.g. on the α-opic irradiances. Test of the spectral sensors compared to calibrated spectroradiometers will also be done and presented.

4. Conclusions

An instrumentation system to monitor and log the spectral characteristics of the light in hospital rooms over long term during a trial of the effect of controlled lighting on patients has been described. The spectral sensors applied full fills the requirements of being small and unobtrusive, and inexpensive allowing many measurement positions and continuous logging.

SPATIALLY RESOLVED DATA FOR HUMAN FACTORS RESEARCH

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Abstract

1. Motivation

The majority of indoor lighting experiments focus on the investigation of human perception of luminous environments at a specific position or in the overall space. For example, the impact of a certain light distribution on the perceived brightness at a workplace, or the subjective assessment of modelling properties of lighting conditions for a pleasant appearance of objects, humans and spaces, are well-known but still present topics in current indoor lighting research. Although lighting researchers examine these criteria since several decades, it is still partly unclear how the subjective responses of experiment participants are linked with lighting metrics. This is due to several reasons. First of all, and in compliance with actual research opinion, the process of light perception in consideration of objects, humans and spaces is still not fully understood, while several approaches exist side-by-side, but none of them draws a whole picture. A comprehensive understanding of how lighting and especially light distributions affect humans' perception of an indoor environment is unavailable. Secondly, in most cases, the research questions deal with a three-dimensional geometry like a space, a work environment or a setting of objects. However, research designs are usually based on established lighting parameters like illuminance and luminance values at two-dimensional planes or surfaces, in order to match participants' responses as a dependent variable to it.

There is a slowly increasing interest in dealing with three-dimensional metrics, such as the illuminance measured in more than just one orientation or 360 degree luminance or illuminance maps at a certain point. Knowledge about the dynamic and levels of these measures is still rare and raises more questions than gives answers, while its spatial consideration is still missing. The mentioned examples differ from conventional parameters not only by their three-dimensional orientation. They also switch the focus from characterising a source, for example a reflecting surface, to the characterisation of the light arriving at a receiver, for example a human eye. If the incoming light at a certain point is characterised as a function of amount and direction, researcher can relate their findings to a powerful dataset, which enables them to find the truly linked lighting parameters to subjective responses. This offers new opportunities to investigate spatial criteria of interest.

2. Methods

We defined a new model that describes the inciding light over a whole virtual sphere at a point in question as a function of amount and direction, which is called light incidence. The approach is linked to the idea of measuring illuminance values in diverse directions at a point in space, but is superior in its information content, because it avoids cosine correction and multiple considerations of same proportions of arriving luminous flux by using a solid angle limitation at the receiver. We investigated this model with measurement and simulation methods for a set of nine light-and-space-situations, where the incidence direction and the proportion of diffuseness was varied. In order to examine the power of these spatial datasets, we tested the model with both methods in two different spatial resolutions by using two different fixed conical solid angle sizes (14 and 24 degree opening angle), which result in one more simple and one rather advanced spatial data pattern with 56 and 188 measured directions at a point. To characterize the luminous environment in the overall space, we measured the spatial data at 27 positions in a regular spatial grid with dimensions in length, width and height that represents the whole room.

3. Results

The results of this kind of light measurements form a spatial light incidence solid, which gives information about the amount of the arriving proportion of the luminous flux from diverse directions. The maxima in each solid give the information about the directions of the main light incidence, while the diffuseness can be estimated by the ratio of the lower values—resulting from reflected light—to the much higher ones, which result from direct light due to short distances and no reflection loss. These

direct and reflected components can be easily derived from two separate simulations, one with and one without internal reflection. The comparison of solids determined at different positions gives information about the change of both parameters, the incidence direction and the diffuseness, throughout the space.

The results also show the advantage of the spatial pattern with higher resolution and smaller solid angle. It considers all information of the spatial light distribution and room geometry and does not leave out any light source position. This is not guaranteed by using the lower spatial resolution which contains bigger gaps in the pattern.

4. Conclusions

We defined and investigated a new receiver-related model that considers the inciding luminous flux as a function of amount and direction without cosine correction and link to material properties. We tested both measurement and simulation methods to get three-dimensional solids of light incidence at a point in question as well as in a spatial grid that represents a space. With the help of these powerful datasets we are able to quantify the light incidence direction in the environment as well as the proportion of diffuseness at a point and in the space. Furthermore, our method can be used as a starting point for the investigation of further three-dimensional lighting criteria. In order to match subjective responses to conventional parameters like illuminance or luminance values at objects at the position of the measured points, one can calculate these from the light incidence solid by adding cosine correction or multiplying with reflection properties. In addition, it can be valuable to use the luminous-flux-per-direction information directly to examine direction-related measures at the human eye, for example in the investigation of glare or non-visual effects.

CHARACTERIZATION OF OCULAR SYSTEM AGING IN LIGHT AND LIGHTING STUDIES

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Abstract

1. Motivation, specific objective

The aim of this study is to propose a methodology for the characterization of the ocular aging of participants in light and lighting studies through proven optometric and ophthalmologic tests. Most of the studies in the field characterize subjects in terms of age, not ocular aging. This might represent a problem as the ocular system might age at a different pace for different subjects and ethnics, particularly for mature participants, but the prevalence of myopia and maladies such as diabetic retinopathy in modern societies affects also the younger populations.

2. Methods

We propose the characterization of participants based on two main criteria, functional and structural status of the ocular system. The functional characterizes the operational status of the system, particularly for the visual function. The structural gives information about the status of the organs and tissues independently of the functional status, and/or compensation mechanisms that subjects can develop.

3. Results

As for the functional characterization we propose to consider techniques such as visual acuity, pin hole, visual field, contrast sensitivity and binocular vision (stereopsis), color discrimination, intraocular and extraocular movements, pupil behavior, and microperimetry (with SLO). These tests will provide a wide characterization of the visual function.

In terms of structural, we have to differentiate between the optical system (cornea, lens, and vitreous humor), and the retina and its vascularization. Tests such as cornea tomography, wavefront aberrometer /topographer, endothelial count, axial length of the eye by optical biometry, macular OCT, wide field OCT, angio OCT (macula and optic nerve), and the ganglion layer OCT are proposed.

Cost and general availability of the different tests are discussed.

4. Conclusions

We will discuss the different ocular parameters and test methodologies, and its association with the performance of the ocular system to properly characterize subjects in light and lighting studies. We hope to contribute to the field of research of methods for human factors in lighting, bridging an existing gap in current research practice.

DETERMINING PERSONAL LIGHT EXPOSURE AND OCCUPANT'S VIEWING DIRECTION BY USING THE NON-OBTRUSIVE LOCATION-BOUND-ESTIMATIONS (LBE) METHOD

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Abstract

1. Motivation, specific objective

Every individual is different suggesting that every individual responds differently to light. This is the main reason why measuring at the individual level is essential when investigating light effects individually. Personal lighting conditions can be determined using person-bound measurements (e.g., actiwatches, light loggers) or via location-bound measurements. A novel practical method (Location-Bound Estimations, i.e. LBE) was developed to estimate personal lighting conditions based on reference measurements. However, these estimations are just based on the reference locations and on the desk location of the office worker inside the office. The actual position of the office worker and its viewing direction is still not included in the LBE method. The aim of the current study is to investigate the differences in light exposure based on different viewing directions (i.e., towards the window, parallel to the window) and the gain in accuracy of the LBE when incorporating the occupant's viewing direction into this method.

2. Methods

A workplace within a larger office landscape was simulated under laboratory conditions. A virtual window emitted light in five different correlated colour temperatures (CCT, i.e. 6000 K, 6500 K, 7500 K, 8500 K, and 9000 K) and was placed closer (i.e., 1.0 m) and further away (i.e., 2.4 m) from the simulated occupant's viewing point. In addition, a dimmable TL office light (providing a horizontal illuminance of 300 or 500 lx at the viewing point) was placed at different locations 1.45 m above the viewing point (i.e., 0 m, +1.5 m, -1.5 m where a negative distance means a location in between the viewing point and the virtual window). These four different aspects (i.e., virtual window – CCT and distance, tubular fluorescent light – illuminance and position) resulted into 65 different office configurations for which the influence of viewing direction on light exposure was investigated. At the position of the simulated viewing point, horizontal illuminance, vertical illuminance, CCT, and general colour rendering index (CRI) were measured. In addition, light spectrum was measured in 16 different office configurations.

The spectral data was analysed using the irradiance toolbox. The five different α-opic values (i.e., cyanopic, melanopic, rohodopic, chloropic, erythropic) were obtained. All absolute measured data and the α-opic values were transformed into relative data meaning that the highest effective radiant exposure (for a specific office configuration) counts as 100% (for example at the viewing direction of 0°) and the effective radiant exposures at the other viewing directions were expressed as percentages of this maximum 100% value. Differences between the five α-opic values and differences between the 65 office configurations were investigated, all regarding the different viewing directions.

In addition to that, light measurements were performed in an office room including daylight. These measurements were to validate the findings from the simulated office experiment. Similar to the other experiments, the measurements were carried out for different viewing directions. Four fibers were used to measure light exposure at four viewing directions simultaneously. The viewing directions investigated were straight to the window, parallel to the window (both sides) and facing straight away from the window.

Finally, the office room including daylight was simulated to extend the research. The aim for the simulation study was to investigate the differences in light exposures for all different viewing directions and all positions inside the office environment. These simulation results will ensure a better understanding of the measurements in the real office environment. The secondary aim was to

potentially identify the optimal office configuration regarding light exposure and its influence on human health.

Combining the results of the laboratory study, field study and the simulation study will result in certain weighing factors per different viewing direction. These factors can be added to the original non-obtrusive LBE method in order to increase its accuracy.

3. Results

The data analysis of this experiment is still in progress. It is expected that weighing factors can be determined for each viewing direction and that these factors can be included in the LBE method in order to increase its accuracy.

The results will be presented at the CIE workshop in August 2018 in Copenhagen.

Advanced Measurements

IMPACT OF LIGHT INCIDENCE AND INCIDENT RADIANT FLUX ON ACUTE ALERTNESS

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Abstract

1. Motivation, specific objective

Studies under nighttime conditions addressing melatonin suppression and phase shift as well as research into the human retina showed that the intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) are not evenly distributed. Their density respectively their sensitivity is highest at the lower and at the nasal part of the retina. Beyond that, binocular illumination is more efficacious in melatonin suppression if compared to monocular illumination. In addition, the human anatomy limits the visual field, e.g. light coming from 60° above gazing direction is blocked. In a shared office with standard dimensions this means ceiling luminance makes nearly no contribution to the illumination of the retina, presuming a fixed horizontal viewing direction. Up to now, the integral measured quantities, illuminance or melanopic-weighted irradiance are being used by most research looking into non-image forming (NIF) effects, to represent the amount of light at the eye level. These quantities are defined to take light respectively optical radiation from anywhere of a hemisphere into account, normally cosine-responding. Our earlier analysis of lighting scenes confirmed that scenes with the same vertical illuminance can have very diverse luminance pattern within the measured hemisphere as well as in the visual field. This might influence the effective radiation for non-image forming (NIF) effects. Resulting, it is questionable if the illuminance at the eye is the adequate measure to quantify the light's potential to induce NIF effects. This could help explaining why research on NIF effects is inconclusive, even though reported lighting conditions are alike. We described a theoretical approach to define the effective radiant flux for stimulating the ipRGCs, taking into account a spatially resolved sensitivity. Despite scares and not yet substantial research on retinal sensitivity, this methodology is easily adjustable when areas with particular sensitivity are determined. Hereon we developed a luminance camera based methodology to evaluate the spatially resolved illuminance and melanopic-weighted irradiance contributions of defined areas in the field of view to the overall vertical illuminance and melanopic-weighted irradiance at the eye. The idea of a future study is to investigate the impact of different luminance distributions with the same illuminance and the same melanopic-weighted irradiance at the eye on NIF effects, in this case acute alertness. Whereas the results might be used to validate the impact of light's origin on nighttime NIF effects (here acute alertness), they will also give insight into the importance of this design parameter on acute alertness during daytime.

2. Methods

The idea of this study is to expose subjects to different lighting scenes in an office-like test room. The experiments will be conducted at day- and nighttime. Our previous analysis indicated what specific luminance distributions can be more effective in causing NIF effects, when a higher sensitivity or density of ipRGCs in specific retinal areas or a higher effectiveness through illumination of both retinas is assumed. From this, two very different luminance distributions in the visual field will be defined. One lighting scene with assumed high and one lighting scene with assumed low NIF efficacy; both with the same illuminance, respectively melanopic-weighted irradiance, at the eye. These luminance distributions will be adjusted to three absolute levels: a dim, a medium and a bright light condition. The medium level will be the 'bright' nighttime and the 'dim' daytime level. The spectral power distribution (SPD) respectively the correlated colour temperature (CCT) of the light source will not be modified. Acute alertness will be assessed in both the night- and daytime condition. A pilot study, preceding the main study, should address the following questions: Which method is adequate for measuring acute alertness in a setting investigating the impact of light's origin? Which illuminance levels are suitable to induce and detect daytime and nighttime NIF effects? For the preliminary experiment a setting in one hemisphere of an integrating sphere with chin rest, fixation of the viewing direction and their supervision by eye tracking is planned. Participants will be exposed to different luminance distributions in the visual field with – based on our method – high and low assumed NIF efficacy and different

absolute levels of illuminance, respectively melanopic-weighted irradiance, at the eye. SPD and CCT will be kept constant. Conducted as well under day- and nighttime condition, acute alertness will be assessed.

Following some of the questions, we would like to discuss and get feedback on:

- Which illuminance levels are appropriate (idea: night 100 and 500 lx; day 500 and 1000 lx)
- Which spectral power distribution should be used? Is a standard LED spectrum (CCT=4000 K) best or does it make sense to use higher CCTs or blue-enriched spectra?
- Which measure/method is suitable to assess acute alertness? What are the experiences and which pitfalls should be avoided?
- What are the experiences if compared audio- and questionnaire-based methods to assess acute alertness?
- Which time of day is best (forenoon or afternoon) to assess daytime NIF effects or more precisely acute alertness?
- How long does the exposure has to be to detect an impact in day- and nighttime NIF effects or more precisely acute alertness?
- Is it reasonable to stress participants prior to and/or while the exposure?
- Which measure is appropriate for daytime NIF effects? Which method is reliable? Are there reliable physiological parameters?
- Is it useful to determine the melatonin suppression in the nighttime condition in addition to the acute alertness?
- Could it be that for each NIF effects different areas in the human retina are sensitive?
- How many participants are needed? How intense will be the influence of the light's origin on the acute alertness?

3. Results

Results of the pilot study are expected by fall 2018 and preliminary results of the main study are expected in summer 2019.

4. Conclusions

This study will give insight into the impact of light's origin on acute alertness during day- and nighttime.

PRACTICAL ISSUES IN FIELD STUDIES USING LUMINANCE CAMERAS

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Abstract

1. Motivation, specific objective

Generally, the lighting design community focuses mainly on illuminance; however, the luminance distribution is more relevant as it relates directly to the brightness perception. This might be one of the reasons that illuminance preference studies fail to find consensus. Nonetheless, the illuminance is, traditionally, more easily measured compared to the luminance. Fortunately, with current technologies it has become a lot easier to measure the complete luminance distribution at once.

In this research, we aim to use luminance distributions, as multiple lighting quality aspects originate from the luminance distribution, as input for a control algorithm that provides human centric lighting. The luminance distribution is measured using the High Dynamic Range (HDR) technology using low cost components (camera and fisheye lens), while maintaining a practical accuracy. This technology enables us to capture images where the pixel values directly relate to the luminance values of the photographed scene. Therefore, luminance distribution measurement devices can be used to measure continuously in field studies, introducing a number of issues unique for field studies.

2. Results

A number of practical issues arise from using luminance distribution measurement devices in field studies, especially when measuring continuously, relating to privacy and accuracy, respectively.

Using cameras in field studies, to measure the luminance distribution, can be quite complex because not everybody (e.g. visitors) can formally be asked for consent while they are being photographed at a regular interval. Additionally, the question arises on how to store the data. One possibility is to only store the required data coming from the luminance distribution; however, this can potentially lead to loss of valuable information, but it can eliminate concerns about privacy. On the other hand, all data from the luminance pictures can be stored, guaranteeing that no information is lost, but this may raise privacy concerns. In addition, it is important to think of where to store the data (e.g., local or in the cloud).

Secondly, in fields studies multiple artefacts are introduced that potentially influence the accuracy of the measurements. Generally, the luminance distribution is measured from the seating position of the user. For continuous measurements in field studies this is not feasible. Therefore, the devices need to be placed at suboptimal positions. There are two distinct strategies for the placement of the device: in the ceiling similar to other frequently used sensors, or at an environment specific location that most closely approximates the seating position without bothering the local processes. The most suitable solution is also related to the specific objective of the measurements. For instance, glare measurements from a point of view on the ceiling tend to be problematic as they would not necessarily record the luminance values experienced from the user's viewing direction. Moreover, the measurement interval is a critical design aspect: a very short interval might cause a sheer amount of data that might have a little relevancy, while a longer interval might miss relevant data. It depends a lot on the fluctuation in daylight, which may best be addressed with dynamic measurement intervals. The measurement interval also relates, to a certain extent, to the privacy of the users as a very short interval might be able to track the users every move.

Finally, the resolution of the luminance distribution relates to both issues. A high resolution image allows a higher accuracy when calculating the lighting quality indicators but might invade privacy as this can, in principle, allow face recognition. Oppositely, a low resolution might introduce inaccuracies for certain lighting indicators, for instance, a glare source is spread out over a larger area. While a low resolution limits the amount of privacy sensitive data that is captured.

3. Conclusions

The luminance distribution has the potential to determine lighting quality measurements in real situations. Theoretically, the luminance distribution can be measured using only low-cost components; however, due to the environmental conditions some concessions might be required that can go at the expense of the accuracy. Additionally, some arrangement might be required to guarantee the privacy of the building users. Concluding, the practical implementation of luminance cameras is a ‘tug-of-war’ between privacy and accuracy.

HIGH DYNAMIC RANGE IMAGES CALIBRATION FOR LUMINANCE MAPS CREATION

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Abstract

In the field of lighting, High Dynamic Range Imaging (HDRI) is a technique increasingly used to study the visual environment. HDRI allows to create luminance maps of the visual field, namely 180° views that include the luminance value of each pixel. The technique consists in capturing multiple exposures of a scene and assembling them together in an HDR image with a wide range of luminance. These HDR images are then analyzed to derive lots of useful information such as glare sources or luminance distributions of areas of interest. An additional benefit of HDRI is the possibility to create luminance maps from affordable equipment. To capture the LDR images series from which the HDR image is derived, only a digital camera and an appropriate lens are required. But creating HDR images with commercially affordable equipment requires an extensive calibration process to ensure that luminance data and derived spatial information is correct. This is the reason why HDRI is also a double-edged sword; several steps could go wrong and HDR images providing wrong luminance values could be generated. This can happen when wrong camera settings are chosen, or due to a miswritten header, an imprecise calibration calculation, or a defect in the equipment. Used in the development of indices and models, these inaccurate luminance maps could lead to non-reliable results.

This paper aims to present an overview of the HDRI calibration process. From the equipment characteristics assessment, through the capture of multiple exposure photographs, the response function derivation, the HDR image generation, the chromatic correction, the vignetting correction, the reprojection, the calibration adjustment by spot luminance measurement, and the Evalglare-ready images preparation, each stage will be addressed. Fully automated methods are more often chosen by researchers than the step-by-step manual method to calibrate HDR images. However, the authors believe that conducting the calibration process step by step allows to have a better understanding of the transformations that are applied to images. Inaccuracies and miscalculations can thus be more easily detected and corrected.

A thorough description of each stage, including requirements, options, and attention points will be provided. Several common and less common mistakes, and how to avoid them will be discussed and useful references to existing literature will be given. Moreover, a special focus will be laid on the geometrical calibration stage, as this topic has seen little attention in the HDR literature. The geometrical calibration, namely the reprojection of HDR images, is only required when generating 180° views which are captured using fisheye lenses. Fisheye lenses project 3D scenes on 2D images with a specific projection type, such as equidistant, equisolid, orthographic, or stereographic projections. According to the projection type, the solid angle and the position of each pixel in an HDR image vary, which influence for instance the calculation of vertical illuminance or glare indices. Each lens model has its own theoretical projection type but each suffers from small inaccuracies. Defining the exact projection function of the lens is essential to derive the right distortion function, namely the function transforming to an equidistant projection, the most common projection type. In order to minimize the imprecision of HDR images, a rigorous calibration work is needed.

EYE-TRACKING FOR HUMAN FACTORS LIGHTING RESEARCH

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Abstract

1. Objective and Motivation

This abstract proposes a discussion and practical demonstration of mobile eye-tracking as a valuable method for the lighting researcher.

Vision is the most dominant of our five senses, using over a third of our brains. Our gaze behaviour can provide insights into aspects of human behaviour, including cognition, perception and social interaction. Gaze behaviour can also reveal much about our experience of the environment. Understanding gaze behaviour is particularly relevant to lighting research as light and vision are inextricably linked - we cannot see without light, and lighting can influence what we perceive. A major reason why the eyes provide a window into our cognition is because we move them to look at areas of interest or significance, thus providing the researcher a glimpse into processes related to attention that are otherwise hard to observe. The reason we move our eyes in this way is because the cone photoreceptors that allow us to see details and colour in the environment occupy only a small area at the centre of the retina. To observe an object in detail we therefore need to direct this central region of the retina, the fovea, towards the object.

It is difficult for us to accurately report our own eye movements and to describe what we have looked at from memory. Simply asking people about what they look at or how they observe an environment, in isolation, is inadequate for scientific purposes. Fortunately, eye-tracking methods have been in development since the 19th century. Video-based methods using pupil and corneal reflections are currently the most popular methods for tracking eye movements. Traditionally, eye-tracking has been carried out in the laboratory as despite continuous improvements the technology can be sensitive in its operation and testing in the lab helps control conditions and ensure a reliable record of eye movements is obtained. However, recent developments with the technology have made mobile eye-trackers (e.g. SMI Eye Tracking Glasses, Tobii Pro Glasses) an accessible option for researchers. These allow gaze behaviour to be recorded in real-world situations, outside the laboratory, and during realistic tasks.

2. Methods

Eye-tracking in real-world situations has a number of advantages over lab-based eye-tracking. First, gaze behaviour is heavily driven by the external features of the environment and real-world situations therefore offer the range of dynamic stimuli that will produce realistic eye movements that may not be captured in a more sterile laboratory environment. This may make the research more generalisable and reflect actual gaze behaviour in natural situations. Second, gaze behaviour is also heavily driven by the demands of the task currently being carried out, and such task demands may be more realistically recreated in real-world situations compared with laboratory conditions. Third, the dynamic nature of real world environments means repeat exposure to the same conditions are limited. This is less so in laboratory experiments, where participants may be exposed to the same test conditions and environment a number of times. Such repeated exposure is likely to artificially influence gaze behaviour over time as the participant learns about and becomes habituated to the test environment.

Limitations also exist with recording gaze behaviour in the real world. Eye-tracking in natural situations is logistically more difficult than eye-tracking in the laboratory, as test conditions cannot be carefully controlled and eye-tracking reliability may be compromise. Environmental factors such as sunlight can also hamper efforts to obtain high quality eye-tracking records. Furthermore, one of the key strengths of eye-tracking in the real world - the realistic experience of dynamic stimuli - can also be one of its limitations. It is more difficult to control the conditions that participants in real-world situations are exposed to, and therefore to isolate the effects of certain aspects of the environment on gaze behaviour. Two methods of analysis - the probability of fixation approach and the critical fixation approach - can be used to partly overcome this limitation.

3. Results

The probability of fixation approach to analysing eye-tracking data takes into account how exposed participants may be to different aspects of the environment, when assessing the importance of gaze towards those features. For example, a feature that occurs more frequently in an environment may be more likely to be observed than a feature occurring less frequently. This can be frequency of occurrence over time based on the number of times the feature is visible to the observer, or spatial presence, based on how much of the observer's visual field the feature occupies. Calculating the probability that a feature is fixated by accounting for its exposure in a participant's field of vision can provide a more meaningful representation of that feature's effect on gaze behaviour, than the more common approach of only looking at the total proportion of fixations towards the feature.

The critical fixation approach to analysing eye-tracking data assumes that not all fixations are equal - we allocate more attention to what we are looking at if it is important or significant. There are many instances when we may not be able to recall at all what we have been looking at, if our attention is elsewhere, e.g. during mind-wandering episodes. Identifying 'critical fixations', when our attention may be increased towards our visual environment, can provide useful information about gaze behaviour and cognition. One method for identifying these critical fixations is to use a concurrent task as an ongoing proxy measure of attention levels. A drop in performance in the concurrent task may indicate a diversion of attention away from this task, potentially to something significant in the visual field.

4. Conclusions

Eye-tracking is a rapidly developing research method, offering objective insights into perception and cognition for the lighting researcher. Recording eye movements in real-world situations can help ensure research is generalisable and reflects realistic environments. This is particularly relevant to lighting research, as our experience of lighting conditions may vary depending on the nature of our environment. In this workshop I will give a practical demonstration of mobile eye-tracking technology, including a method for identifying critical fixations.

Psychophysics

LUMINANCE DISTRIBUTIONS SET BY USER-CONTROLLED LIGHTING: THE OPTIMAL METHODS TO MAINTAIN SATISFACTION WHILE SAVING ENERGY

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Abstract

1. Introduction

In large open-plan offices, the energy consumption for lighting can be reduced by dimming luminaires based on individual occupancy. By distinguishing between a task, surrounding, and background area, the lighting can be optimized to the occupancy scenario at hand. The resulting luminance distributions need to be in line with users' preferences to maintain their comfort. Therefore, lighting research typically asks users to set the lighting, but the methodology used for this task has been found to influence the results. For example, studies showed that with a smaller stimulus range, participants chose lower settings. While this positively affects the energy use of lighting, satisfaction levels were not negatively affected. Thus, with the right methodology, it is possible to optimize energy usage while maintaining satisfaction when asking users to set the lighting. This study investigates with which methods these aims can be accomplished for preferred luminance distributions in large open-plan offices.

We investigated three methodological issues, namely (1) start dimming level, (2) adjustment method, and (3) distribution area. First of all, to obtain preferred luminances in the task, surrounding, and background area, users need to set three dimming levels, which poses the question which should be asked first. This is challenging, because they interdepend on each other. Typically, lighting research fixes one level, e.g. the surrounding luminance, and asks participants to set the other level, e.g. the task luminance. However, this approach is not ideal. For example, when the task luminance is fixed at certain values, some users are likely to be dissatisfied already; they might compensate for this dissatisfaction by the settings in the surrounding and background area. This restrains us from revealing their true luminance distribution preferences. Hence, in the ideal case, participants are provided control over all three areas, but this might be too complex for them as it results in an almost infinite amount of choices. Another possible approach is to provide participants subsequent control over the three areas, which we investigated in this study.

Secondly, the "adjustment method" influences the outcome of preference studies. This method refers to the stimulus range and anchors employed for the task of setting the lighting. Lower anchor levels typically result in lower chosen settings; hence, it is relevant to investigate whether satisfaction levels can be maintained compared to when high anchor levels are employed.

The third issue is related to the concept of utilizing different dimming levels across an office space. In a large open-plan office, the definition of the surrounding area is not straightforward. While medium-sized offices typically contain just one desk group, representing the surrounding area, larger offices typically contain multiple desk groups. Hence, we tested two scenarios: one where the surrounding area was limited to the desk group of the occupant, and one where it included all luminaires in the space except those along the walls.

2. Methods

We employed a 2 (Start level: surrounding versus background level) × 2 (Adjustment method: increasing versus decreasing) × 2 (Distribution scenario: 5 versus 14 surrounding luminaires) repeated measures design. With the increasing adjustment method, participants started from the output level that provided ± 100 lx at all desks in the desk group of the participant. When decreasing, participants started from the maximum output level (± 800 lx). Dependent variables included room appraisal (representing satisfaction) and relative energy use. The experiment was conducted in April of 2017 on weekdays. Each session included one participant at a time with a duration of 1,5 h in total. 42 participants completed the experiment (23 females, 19 males, age range 18-24). The research was

conducted in a darkened open-plan office space (8.6 x 10.2 m). Participants were asked to set the lighting through an interface on a PC; they could adjust the lighting levels with up and down buttons.

3. Results

We compared both satisfaction and energy use between the levels of the three factors.

Between the two start levels, room appraisal differed significantly ($F(1, 454) = 10.22$, $p = .001$*): when participants started with setting the surrounding level (EMM = 45.72, SE = 1.24), they appraised the room higher compared to when they started with the background level (EMM = 44.75, SE = 1.25). Energy use did not differ between the two levels.

The adjustment method significantly affected the energy use of participants' chosen levels ($F(1,588) = 81.62$, $p = .000$**): these were significantly lower when participants increased them from the minimum level (-10.21%, SE = 3.41) as compared to when they decreased them from the maximum level (+ 4.97%, SE = 3.34). Room appraisal did not differ between the two adjustment methods.

Across the two distribution scenarios, both room appraisal and energy use did not differ significantly.

4. Conclusions

This study determined the optimum methodology to maintain users' satisfaction while optimizing energy use when asking users to choose their preferred luminance distribution in a large open-plan office. The results indicated that this includes asking users to start with setting the surrounding level, and from a minimum level. No differences were found between the two groupings of luminaires, but we suggest to employ a surrounding area that pertains to the desk group of the present occupant from a practical point of view. The findings apply for a relative young population representing office workers with no limitation in their visual functioning. In the future, the study needs to be replicated with other age groups of office workers.

PHYSIOLOGICAL RESPONSES IN RELATION TO GLARE: A CASE STUDY IN OFFICE SETTING

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Abstract

The modern work setting is tailored to productivity, health, satisfaction, and comfort. A recognized factor that reduces productivity in workplaces is discomfort glare. While perception of objects may not necessarily be impeded, discomfort glare affects the observer with experiences of discomfort, fatigue, and headaches. So far, we know that the main human responses to discomfort glare are psychological and subjective negative responses. Therefore, quantification of discomfort glare proves to be a challenging task.

In quantifying the perceived glare, the existing models for glare analysis are driven by photometric measurements in the user field-of-view and subjective evaluation. Measuring visual discomfort through subjective and self-reported evaluations that prevail, has been widely criticized for the intrinsic uncertainty of these methods, the de Boer glare category rating scale an example. The visual discomfort reported by participants can be attributed to luminance distribution and a wide range of factors including but not limited to user background or biological differences. Consideration of biological reactions and ocular behaviour, may permit a parallel objective means of determining discomfort glare and reducing the uncertainties about category rating scale assessment.

Several studies have already addressed light induced ocular behaviour such as pupil dilation and degree of eye opening in different lighting conditions. Research to date has not yet determined whether, and to what extent, objective measures of human ocular reactions and light induced gaze behaviour are affected by glare in a working environment. In this research, an experimental study was performed to investigate these factors in detail. The experiment was carried out on the Gold Coast, Australia, in a cellular office with north-west orientation and high proportion of glazing. In this experiment, four lighting conditions with different discomfort glare levels and light distribution were determined as independent variables. Participants were asked to perform different types of office visual tasks while their eye and gaze related data were recorded in conjunction with photometric measurements.

A lightweight eye-tracking device was used to provide gaze and ocular behaviour data that was subsequently incorporated into a visual performance analysis. High-dynamic range (HDR) imaging was used, as a luminance mapping technique, to record the luminance distribution in a room and also provide input to existing glare models. To provide a better understanding of user ocular behaviour, a subjective evaluation of user sensitivity to glare using the Rasch rating scale, was performed prior to commencing the experiment.

The results indicate that the pupillary oscillation and the number of blinks when participants are exposed to glare was more significant in later phases of the task. It was also found that the magnitude of fluctuation of photopupillary reflex are task dependant. Moreover, in a same lighting condition, the Rasch rating scale highly justifies the different physiological responses and reported glare by users.

Discrepancies exist between predictive models and user perception. In order to provide a predictive model that more realistically acknowledges issues of human subjectivity and behaviour, it is beneficial to add more quantitative measurements in conjunction with predominant glare research method (using subjective evaluation and luminance mapping) which are involuntary and independent of judgement and bias. In the next step of this study, physiological responses along with visual performance will be examined.

METHODOLOGICAL AND ANALYTICAL BIASES IDENTIFIED IN STUDIES OF GLARE DUE TO DISCOMFORT

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Abstract

According to the International Commission on Illumination (CIE), discomfort glare is a sensation usually caused by high luminance or luminance contrast within the field of view that is sufficiently greater than the conditions to which the eyes can adapt to. To help lighting designers limit the levels of discomfort caused by glare sources in buildings, several predictive models have been developed that are proposed in the scientific literature and recommended by international standards. Although models have been designed to provide precise evaluations of discomfort for any given condition, many studies have found that this is not always the case. When models are used to describe the degrees of discomfort with subjective evaluations given by observers, a large spread in the data is usually found.

One factor limiting a better characterisation of the degrees of discomfort produced from glare sources is an insufficient consideration of the methods and statistical procedures that have been used. In this study, we highlight several types of methodological and analytical bias associated with two procedures that have formed the basis of predictions models used to evaluate glare due to discomfort: *luminance adjustment* and *category rating*. In the luminance adjustment, the experimenter or observer varies the brightness of the source or background until several predefined criteria of discomfort have been met (i.e., Just Imperceptible, Just Acceptable, Just Uncomfortable, and Just Intolerable glare). In the category rating, the observer has little or no interaction with the visual scene, but instead are asked to allocate one of several criteria, which present an alleged degree of discomfort.

In a series of laboratory tests, several experiments have been carried out to identify sources of method bias when using either procedure. When using the luminance adjustment, the final setting made to a glare criterion is biased towards the initial luminance used before the adjustment task (heuristic anchoring). Results showed that the use of different luminance anchors produced notable differences on the final settings made to the same criteria of discomfort. When adjustments to multiple glare criteria are performed in a strict sequence (i.e., first to the lowest criteria, and then to the others in increasing order of discomfort) this can create an ordering bias. When using difference sequences, however, the ordering bias only appeared to influence settings made to the lower glare criteria and not to criteria relating to higher levels of visual discomfort. When a pre-trial demonstration is used (i.e., a range of luminances used to present the lower and upper limits of the glare source) before adjustments are made, higher settings to the same criteria of discomfort are given (range bias). Lower settings are found when an independent group were not given the same pre-trial demonstration. Similar influences were also found when the pre-trial demonstration is performed in the category rating procedure. Based on different ranges of luminance presented in a pre-trial demonstration, this influenced the evaluations of discomfort given to the same fixed glare settings that were rated.

When replicating study findings, it has also been shown that the methods used to analyse the data can also play a vital role on the conclusions drawn from an experiment. In all studies used to derive the thresholds of discomfort in predictive models of glare, frequentist approaches that relied heavily on significance testing (*p*-values) are used to support or reject experimental findings. Since these approaches are not designed to compare the findings from data derived from multiple studies, this has often led to misleading conclusions. In a study carried out to examine the effect of order on discomfort produced using artificial daylight, an alternative Bayesian approach was used. This analysis utilised previous knowledge obtained from a past study that was then compared against data derived from a new experiment, using the same hypothesis and test procedure but with an independent sample of observers. Bayes Factors could then be calculated as a substitute for significance testing to determine how close the findings across two studies agreed with each other. The findings showed that in most cases, similar glare settings made when performing the luminance adjustment were influenced by the same effect of order in both experiments. Since the Bayesian approach has been designed to direct

compare data derived from past studies, they also offer a suitable alternative of examining the predictive power of existing models of glare against new studies.

While the current models of glare that are used the estimate the degrees of discomfort have not considered these sources of methodological and analytical bias, important questions should be raised to the alleged precision of the formulae that were derived from the original experiments. Based on findings from this investigation, there is a need to propose an experimental procedure that considers these study findings when estimating the thresholds of discomfort. Data derived from these experiments would be analysed using appropriate statistical techniques to derive a new prediction model of glare. A Bayesian approach can be used, estimating parameter estimates (luminances, glare index values, effect sizes, etc.) that would then be updated in consideration of new experimental data. Therefore, overcoming the limitations that have be identified in past studies of glare due to discomfort.

TWO METHODS OF BRIGHTNESS ASSESSMENT AND EXPERIMENTAL BIAS

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Abstract

1. Motivation and objective

The aim of this study is to provoke a discussion about experimental bias in brightness assessment studies. To initiate the discussion two studies on magnitude-estimation are replicated and both are expected to result in the square law curve. The square law curve, which supposedly describes the relationship between relative and perceived light is the basis for behaviour of many dimming control systems. The methods that were chosen for this study were selected based on their earlier use for either loudness estimation and/or brightness estimation. The two methods distinguish from each other by having two different assessment methods for brightness; Method 1 by assigning a number and Method 2 by drawing an apparent length. In Method 1 the assessment is judged in relation to a reference brightness with a given number and without borders for maximum or minimum numbers. In Method 2 there was no reference stimulus to judge against but the length of the paper presents borders for maximum length of a line to be drawn.

2. Methods

The test was conducted in a room (L:8.6m x D:4.6m x H:2.7m) with no daylight access. A total of 25 subjects (age M=25.2, STD=3.1) participated in the study. Thirteen of them started with method 1 and twelve with method 2. Subjects were asked to read the instructions before each of the two methods. During the trials the subjects had a fixed view on the wall. Subjects left the room between each trial. Both methods were tested for two stimulus ranges in randomized order, one with 100% at 1500lx and another with 100% at 1000lx. Null-condition trials were performed for both methods and all light levels were measured on the table.

Method 1 (M1): Brightness assessment by a number in relation to a reference brightness with a given number

This method is based on the recommendations from Stevens for estimation of loudness. The written instructions to the subjects was:

"*The researcher will present the standard brightness to you. We are going to call the brightness of the standard 10 and your task is to estimate the brightness of the following variable. In other words, the question is: if the standard is called 10 what would you call the variable? Use whatever numbers seem to you appropriate – fractions, decimals, or whole numbers. For example, if the variable looks 7 times as bright as the standard, say 70. If it looks one fifth as bright, say 2: if a twentieth as bright, say 0.5, etc.*

Try not to worry about being consistent; try to give the appropriate number to each brightness regardless of what you may have called some previous stimulus.

The researcher will inform you when you are presented with the 'standard' and when you are presented with the 'variable' that you are asked to judge. Let the researcher know if you want to see the standard and the variable again before making your judgement. The process can be repeated as often as you need to, before you decide on your estimate."

The reference brightness, named 10, was 40% of the maximum light levels and the test stimuli were 5%, 20%, 70% and 100% presented in randomized order within both stimulus ranges.

Method 2 (M2): Brightness assessment by scaling of length

This method is based on the work of Stevens and Guirao where they used a screen and a control knob regulated by the subjects to determine the length of a line and the experimenter presented a reference stimulus. This study however used a pen, one A3 sized paper and no reference brightness. Subjects were asked to judge the perceived brightness of a light level by drawing a line which

represents the brightness perceived. The instructions to the subjects were based on the instructions from the original study and were as follows:

"The researcher will present a brightness to you and your task is to estimate the brightness of the stimulus and draw a line that represents the brightness of that stimulus. In other words, the task is: to draw the length of a line so that it's apparent longness matches the brightness of each stimulus.

Try not to worry about being consistent; try to give the appropriate length of a line to each brightness regardless of what you may have drawn for the previous stimulus.

The researcher will inform you when you are presented with the stimulus that you are asked to judge".

The test stimuli were 5%, 20%, 40%, 70% and 100% presented in randomized order within both stimulus ranges.

3. Results, discussion and conclusion

Method 1 assigning a number to brightness resulted in a nearly linear relationship between relative light measured and relative light perceived. The results are unexpected since Stevens' work, using the same method for loudness, resulted in the square law curve. Differences between M1 and Steven's test are e.g. researcher vs. occupant control, behaviour and time of light setting change, surroundings, number of subjects as well as discipline.

Method 2 assigning a line to estimate brightness resulted in data that is not significantly different from the power curve from 40% relative illuminance and higher, using one sample T-test. Stevens and Guirao's study resulted in the square law curve. Differences between the original test and M2 are e.g. use of reference stimulus, use of assessment tools: computer vs. pen and paper, behaviour and time of light setting change, surroundings, number of subjects as well as subject's type of study.

The difference between the two methods is the way the brightness is judged (numerical or by drawing a line), M2 has physical boarders due to the size of the paper, M1 provides a reference, M2 presents the subjects with their previous judgements, M1 has more brightness presentations due to the use of a reference.

Due to the experimental setup it is not clear why the results of M1 and the lower part of the M2 data differ from the square law curve and in principle there are many things that can go wrong. Human error during experiment and analysis being one thing, experimental setup being another. This paper seeks to promote discussion on the use of reference stimulus, boundaries and way of judging as well as other experimental biases in relation to the presented brightness assessment methods.

THE IMPACT OF THE STARTING POINT CHROMATICITY ON MEMORY COLOUR MATCHING ACCURACY

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Abstract

1. Motivation, specific objective

Memory colour, the colour associated with a familiar object in long-term memory, has been used successfully as internal reference in the study of chromatic adaption, colour rendering, and image colour quality. The Memory Colour Matching (MCM) method involves an observer adjusting the colour appearance of a familiar object stimulus under each adaptive condition until it matches the observer's internal memory colour. In determining corresponding colours, MCM allows for more accurate matches than short-term 'learned' memory matching and the method is less time consuming than simultaneous asymmetric matching.

The initial chromaticity of the test objects at the start of each colour match is called the starting point (SP). The chromaticity at the end of each match is called the ending point (EP). In previous experiments, memory colours were determined by averaging the matches resulting from four SPs, equally distributed along the hue circle centred at the familiar object chromaticity when illuminated by an equal-energy spectrum (EEW). However, the influence of the SP on the EP has never been experimentally verified. The goal of the present study is to investigate how the distribution and combination of SPs influence the accuracy of the EP, how this varies amongst observers, and how to achieve a practical trade-off between accuracy and experiment duration.

2. Methods

In the experiment, the stimulus background was a white 3D stage, with several white, grey and black objects, providing an adaptation field of view of approximately 50°. The test stimulus was a 3D grey cube centrally positioned in the background scene. A calibrated data projector was used to provide an easily controlled illumination of the background different of that of the stimulus. The spectral radiance of the background and the cube was measured with a calibrated spectroradiometer.

The target familiar colour 'neutral grey' was adopted in this experiment. Two adapting fields, both with luminance of 600 cd/m^2, have been selected: EEW and a yellowish high chroma illumination. To investigate the influence of the SP, matches were made for 10 SPs which included 8 colourful SPs equally distributed along the hue circle centred at the EEW chromaticity of the neutral grey, 1 at EEW and 1 SP with the same chromaticity as the background. All chromaticity values were defined in the CIE 1976 u'_{10} v'_{10} chromaticity diagram.

During the experiment, observers were asked to adjust, after a 45 seconds adaptation time, the apparent colour of the cube until its appears neutral grey by navigating in the *CIE 1976* u'_{10} v'_{10} chromaticity diagram using a keyboard while the background remained fixed. The track from SP to EP was recorded for each match and each observer for further analysis. The background colours and the SPs were presented randomly within a single experiment session.

Ten observers (7 males and 3 females), all with normal colour vision tested with the Ishihara 24-plate test, participated in the experiments. The average age of the observers was 28.0 years with a standard deviation of 3.5 years.

3. Analysis and results

Firstly, intra- and inter-observer variability were investigated in terms of the mean colour difference from the mean (*MCDM)* in *CIE 1976* $u'_{10}v'_{10}$ chromaticity diagram. The mean inter-observer *MCDM* values calculated for the yellow and EEW backgrounds were respectively *0.0143 and 0.0080 in* $u'_{10}v'_{10}$ units and the mean intra-observer *MCDM* values were *respectively 0.0085 and 0.0062* in $u'_{10}v'_{10}$ units. Both the repeatability and consistency were substantially higher for the EEW background than for the

yellow background. The average $u'_{10}v'_{10}$ chromaticity, obtained by averaging the 10 EPs of all 10 observers, has been used as ground truth.

Secondly, the adjustment tracks from 10 SPs to their corresponding EPs were analysed for each observer and background. In most cases, the track did not tend to cross over the central region towards the complementary hue, especially for experienced observers. Tracks were longest for purple and blue SPs and shortest for the EEW SP.

Thirdly, the impact of the distribution of the SP chromaticity values on the accuracy of the EP was investigated. n SPs were selected randomly from all the 10 SPs. The colour difference between the average of the n selected SPs and the average of the 10 SPs represented the symmetry of the randomly selected SPs around the centre while the colour difference between the average of the corresponding n EPs and ground truth represented the accuracy of the EP. The correlation coefficients between the symmetry of the SPs and the accuracy of corresponding EPs in terms of $DE\ u'_{10}v'_{10}$ were *0.75* and *0.78* for yellow and EEW background respectively. Also it can be found that selecting more SPs leads to higher accuracy. The results demonstrated that the distribution of the SP chromaticity has significant impact on the EP and that more symmetric SP distributions can give rise to a higher accuracy of the EP.

Finally, the trade-off between accuracy and the number of SPs and number of observers was also investigated aiming towards a possible reduction in experiment duration while still retaining accurate and stable results. The analysis was done in terms of the $DE\ u'_{10}v'_{10}$ colour difference with the ground truth chromaticity value. Results showed that 6 observers and 4 SPs were sufficient to obtain accurate and stable results. Compared to a full study with 10 SPs and 10 observers, such experiments would only require about ¼ of the time.

4. Conclusions

To investigate the influence of the starting point chromaticity on the accuracy of MCM, an experiment with 10 possible SPs and 2 backgrounds was conducted. The results show that a more symmetric SP distribution around the centre and a higher number of SPs can lead to a higher accuracy. With regard to the time efficiency of the MCM experiment, 4 SPs and 6 observers seem to be sufficient to achieve accurate results. These results provide well-founded guidance to future applications of the MCM method.

We hope to receive feedback on further investigations and possible improvement of MCM methods aiming towards improving accuracy while saving time.

EVALUATION OF DISCOMFORT GLARE THROUGH GLARE SCALES: WHAT ARE WE REALLY MEASURING?

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Abstract

1. Motivation, specific objective

To collect subjective evaluations of discomfort glare, subjects are usually asked to rate a visual scene on a glare scale. Several glare scales have been defined in the literature, and many replications or derivatives of these scales are currently used. One of the most adopted glare scales is the 4-point Osterhaus' scale – imperceptible/noticeable/disturbing/intolerable –, although scales that use modified versions of the 5 labels from the 9-point De Boer's scale – unbearable/disturbing/just admissible/satisfactory/unnoticeable – are also common. Unfortunately, it is frequent practice by some experimenters to either mix labels from different scales or develop their own glare scale, hence making between-studies comparisons very difficult.

There is a large consensus between researchers that most glare scales are unipolar, going from a "no glare" to a "very glary" end. These scales are usually treated as such in statistical analyses and for their correlation with discomfort glare indices. But, how do the subjects interpret these scales? Up to now, there has been only one study investigating subjects' interpretation of a modified De Boer's scale. The results showed that, besides the confusion brought by the terminology, only 15% of the subjects could reconfigure the labels of the scale in the right sequence.

In an effort to clarify the use of glare scales, the data from two field studies have been analyzed.

2. Methods

Two field studies were conducted in office buildings in Chile and Belgium. The study protocols were the same, collecting objective and subjective evaluations of the luminous environment, and specifically of discomfort due to glare, through a questionnaire translated in the local main language. The questionnaire was divided in three parts: 1) a first assessment of the luminous environment; 2) a set of demographic questions; 3) a second assessment of the luminous environment under different settings of lighting controls.

For the assessment of the luminous environment, the participants were initially asked about their subjective evaluation of the general lighting conditions on a 4-point satisfaction scale. If participants were not fully satisfied with their luminous environment, they could explain the reason(s) in an open-ended question (OEQ). Two glare scales were then presented to the participant, one after the other. The first was a 4-point scale to rate discomfort due to glare: no discomfort/small discomfort/moderate discomfort/large discomfort. The second was a 5-point modified De Boer's scale: imperceptible/perceptible/acceptable/uncomfortable/intolerable.

86 Belgian and 85 Chilean office workers participated in the studies. A dataset of 342 subjective evaluations was used for the analysis.

3. Results

To check the reliability of the two glare scales, the Cronbach's alpha was evaluated. The internal consistency reliability between the two normalized scales was 0.68, which is under the minimal recommended value (0.8). Moreover, the Spearman correlation coefficient between the two scales was 0.53.

Evaluating the distribution of the answers in the two glare scales, an unexpected trend was noticed. Since the data were collected in field studies, and people tend to work under conditions as comfortable as possible, a lower number of evaluations in the scale categories corresponding to "glary" situations was expected. This was the case for the 4-point scale, where the distribution of responses was: "no discomfort", 52%; "small discomfort", 31%; "moderate discomfort", 14%; "large discomfort", 3%. However, for the 5-point scale, the distribution of responses was: "imperceptible", 21%; "perceptible", 16%; "acceptable", 48%; "uncomfortable", 14%; "intolerable", 1%. The 5-point scale might therefore not be interpreted by the participants as intended by the researchers. One reason might be that the participants use the 5-point scale as a bipolar scale with a neutral/no glare condition in the middle. The misinterpretation might also be due to the labels of the 5-point scale referring to two different concepts, namely acceptance and perception.

At last, the two glare scales were transformed to binary scales of discomfort due to glare, to be compared to the responses of the OEQ. The no discomfort category of the 4-point scale included the no discomfort label, whereas the discomfort category included the small, moderate, and large discomfort labels. The division of the 5-point scale was done accordingly to common practice in the literature, namely the imperceptible, perceptible, and acceptable labels in the no discomfort category, and the uncomfortable, and intolerable labels in the discomfort category.

From the participants satisfied with the lighting conditions, 28% felt in the discomfort category when considering the transformed 4-point scale, against only 2% when considering the transformed 5-point scale. From the participants who spontaneously mentioned discomfort glare as a source of dissatisfaction in the OEQ, 95% felt in the discomfort category when considering the transformed 4-point scale against only 40% when considering the transformed 5-point scale. These results could imply, on one hand, that the 4-point scale (or its binary transformation) result in an over-estimation of discomfort due to glare, and on the other hand, that the 5-point scale (or its binary transformation) underestimate discomfort due to glare since 60% of the participants who spontaneously reported glare in the OEQ felt in the no discomfort category. However, these observations could also result from semantic biases affecting the two scales in radically different ways.

4. Conclusions

It was concluded that participants might interpret glare scales differently than researchers, hence providing unreliable answers.

Some recommendations can be given based on these results. First, before asking for a rating on a glare scale, an OEQ should be inserted, since it is the least biased method to recognize whether discomfort glare is a source of dissatisfaction worth mentioning. When using glare scales, experimenters should be clear about what they want to measure: is it the perceived discomfort, or the acceptance of glare? The scales should also be developed in such a way that there is no room for interpretation. At last, the definition of a standard for subjective assessment of discomfort due to glare, such as the ISO 10551 for thermal comfort, would be a great asset for the quality and consistency of future research in this field.

Additional field studies will be conducted with modified methods of assessment of discomfort due to glare, such as the 4-point Osterhaus' scale, for this issue to be further investigated.

BRIGHTNESS ASSESSMENT USING PARTITION SCALING

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Abstract

1. Motivation, specific objective

One of the more commonly used psychophysical methods producing a ratio scale is Magnitude Estimation (ME). Observers assign a numerical estimate for the perceived magnitude (e.g. brightness) of a test stimulus compared to a reference stimulus with a predefined magnitude. ME is frequently used in colour appearance and brightness estimation despite some of the possible issues which have been suggested in psychophysics literature. The occurrence of sequential effects is one of them: the estimated value not only depends on the stimulus under test but also on the recent history of shown stimuli. ME is also highly sensitive to centring bias: the observer tends to centre the range of responses on the range of shown stimuli, which can have a huge impact on the results. Some of these effects or biases are directly linked to observers translating a perceptual sensation into a number.

This research explores an alternative assessment method for brightness perception which is less susceptible to biases and which is called Partition Scaling (PS). This method constructs an interval scale of a psychological attribute (e.g. brightness) directly from the judgment of an observer. It relies on the observer to execute several bisection tasks adjusting the stimulus until the perceived magnitude perception is in the middle of two other given stimuli.

The “progressive solution” proposed by Gescheider in 1997 is adopted. At first, the observer is shown two “anchor” stimuli having an intensity value corresponding with the outer limits of the investigated range. Once the observer has adjusted the luminance of a third stimulus creating two equal perceptual distances, each of both new intervals are bisected again in the same manner creating four equal perceptual distances. Successive equal distance intervals can be obtained by progressively bisecting the intervals into smaller and smaller distances. A psychophysical magnitude function can then be constructed by plotting the arbitrary scale values against the luminance of the stimulus.

2. Methods

A PS experiment for brightness perception was conducted using a calibrated EIZO ColorEdge CG246 LCD monitor, capable of generating a high precision output (10 bits per colour channel). The screen was calibrated using a colour colorimetric camera. Experiments took place in a darkened room with no active light sources apart from the monitor. The observer’s distance to the monitor was roughly 60 cm, resulting in an approximate 40° field of view (FOV) of the monitor and a 10° FOV for centre circular stimulus.

Three circular patches are displayed. The circular stimuli are surrounded by near dark background illumination of the monitor (~0.25 cd/m²). Observers were given the task (bisection task) to change the intensity of the middle circle such that the brightness perception was in the centre of the brightness of the left and right circle. Progressively bisecting a given intensity range by conducted several bisection tasks is denoted as a PS run. Four initial luminance ranges of the outer circular stimuli were selected: range A using the maximum luminance range from 5 to 175 cd/m² and ranges B, C and D characterized by more compact luminance ranges of [5 - 82], [51 - 129] and [98 - 175] cd/m², respectively.

Two separate experiment sessions were conducted. Both sessions were equivalent except in the first session the left circle was always the lowest intensity and the right circle the highest whereas in the 2nd session these were switched so the highest value was now on the left. Before starting a session, each observer performed two short training PS runs using range A as starting intensity range. In each session observers completed 2 PS runs per range, one where for each bisection task the initial intensity value of the middle circle was equal to the maximum luminance of the monitor whereas the other had an initial value of the minimum luminance of the monitor. For each range, a PS run resulted in a total of 8 equal sense intervals. In total each observer completed 8 PS runs per session resulting in 56 bisection tasks, not including training runs.

Fourteen observers – five female and nine male – of 24 to 30 years old (and with an average of 26.4 years) participated in both sessions. Each session took around 30 minutes per observer.

3. Results

Observers could accurately execute the bisection tasks for ranges A and B. However, most observers reported to have difficulties to assess the stimuli in the ranges C and D because the perceptual differences of the stimuli were too close. The results were fitted using Stevens's power law with a constant factor to obtain a relationship between the magnitude of a physical stimulus (e.g. luminance) and its perceived intensity (e.g. brightness). In this work the normalized brightness perception (Q) is defined as:

$$Q = f(L) = aL^b + c \tag{0.1}$$

Where a is a scaling factor, L is the stimulus luminance, b is an exponent and c is a constant. In the literature, reported values of b for brightness are around 1/3 and ½. Fitting the normalized Q values to the observer's adjusted luminance values results in b values of 0.35 and 0.43 with R^2 values of 0.95 and 0.94 for range A and B, respectively.

4. Conclusions

Preliminary results show that PS gives accurate results when perceptual stimuli differences are clearly visible and inaccurate results rapidly occur with small differences. ME is less prone to inaccurate results with perceptual similar stimuli. Another downside of PS is that errors will tend to accumulate as the intervals become smaller. In a future brightness perception experiment, a detailed comparison between PS and ME regarding their performance will be conducted and more details and results will be provided during the workshop upon acceptance.

We hope to receive feedback regarding possible biases, improvements of the PS method and alternative methods.

HOW TO EVALUATE THE « PERFORMANCE » AND « ROBUSTNESS » OF GLARE METICS?

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Abstract

Many research papers have been published in recent years evaluating glare metrics using measured data and subjective responses of subjects. These studies come to different results and conclusions. Besides the fact, that different experimental procedures, measurement uncertainties (e.g. pixel overflow of HDR cameras) and different glare scales could lead to different results, the way to analyse the “performance” of the metrics is also differently.

But how is the “performance” of a glare metric defined? There is no clear rule for this. The idea of this workshop is to discuss several statistical methods to evaluate glare metrics regarding their performance and robustness.

One potential definition of performance is the ability of the metric to correlate with the glare scale, which is the subjective expression of the test persons’ perception of glare. Most used glare scales are of ordinal nature (e.g. imperceptible glare, noticeable glare …). Ordinal data cannot be correlated with the Pearson’s method since it relies on equal distanced independent data. Instead, a Spearman-Ranking-correlation has to be applied to ordinal or categorical data. But how to interpret the results of the correlation? At least three points have to be considered:

1. The magnitude of the ρ-value: Cohen considers a Spearman ρ of >0.5 as large effect size and >0.3 as medium effect size.
2. The difference between the ρ-values between the metrics: Which difference is significant?
3. The p-value: Does the value pass the significance level? The more metrics are compared, the more probable it is that a random effect leads to a wrong ranking between the metrics. For that reason, a correction of the significance levels has to be applied. The most common one for these kind of application is the Bonferroni-correction.

Another possibility to evaluate the performance is the application of diagnostic tests, which are very common in medical research. In a first step, the dependent categorical variable (=glare sensation vote) has to be converted first into a binary variable, e.g. disturbing and non-disturbing glare. Several types of analysis can be done. The Area Under the Curve (AUC-value) describes ability to discriminate between disturbing and non-disturbing glare. Hosmer-Lemeshow describes a AUC >=0.7 as an acceptable discrimination and an AUC >=0.8 as an excellent discrimination for the binary data. Other literature interprets an AUC <0.6 as fail and 0.7>AUC >=0.6 as poor. Also in the case of the AUC evaluation it has to be evaluated, which difference of the AUC values between the metrics is significant.

The diagnostic tests offer also other evaluations: With the ROC analysis, so called cut-off-points can be determined. These describe the borderline between the different categories of glare (e.g. between disturbing and non-disturbing glare). They could be applied multiple times to determine the borderlines between all categories. With these values, the True Positive Rate TPR and True Negative Rate TNR can be determined.

While TPR and TNR seem very intuitive (TPR corresponds the prediction rate of disturbing glare and TNR corresponds to the prediction rate of no or non-disturbing glare), they have to be evaluated with care and only together at the same time. A very high TPR could be reached by having a very low borderline value, causing a low TNR, which means the metric is overpredicting glare. The opposite happens when the borderline value is too high, TNR is very high then and glare underpredicted. This problematic behaviour can be used to evaluate the robustness of the metrics. As robustness we could define, how well TPR and TPR are in case the borderline value was determined with another dataset before.

The SqD is another diagnostic test and is a trade-off between the rate of predicting glare situations TPR and the rate of predicting non-glare situations TNR with giving both the same. The smaller the value the better the metric performs for the used borderline-value. A value larger than 0.5 indicate, that the data cannot be discriminated reliably. If the SqD varies between the different datasets for a metric, then this indicates a sensitivity to the borderline-value and is a measure for the non-robustness of the metric.

The analysis of the probability being disturbed was introduced to glare analysis some years ago. For this evaluation, the dependent categorical variable has to be converted first into a binary variable, similar to the diagnostic test. In the next step, the data are sorted by the independent variable (metric) and then binned. The number of bins and therefore the amount of data points for each bin is arbitrary and influences the results. The reason for this will be shown in the workshop and a possible solution a “floating probability evaluation” shown.

Besides these analysis techniques, data preparation and random sampling will be explained in the workshop. Whenever a model is derived (e.g. determination of regression curves or borderline values), the data have to be split into training data (=dataset to derive the coefficients or borderline-values) and testing data (=dataset, where the performance tests are applied, e.g. TPR, TNR, SqD). If the entire dataset is not huge, the way of splitting the data into training and testing may influence the outcome. In that case it is useful to apply random sampling and repeat the entire procedure several hundred or thousand times, as it is done for bootstrapping as well. An open question so far is, how the differences between performance evaluations between the different metrics is considered as significant, when random sampling is applied the average performance value is compared (e.g. the average SdD is compared between metric A and metric B).

The final goal of the workshop is to discuss different methods for performance and robustness evaluation of glare metrics, as well as to mention statistical methods, which should not be applied (e.g. Pearson correlation, accuracy evaluation of diagnostic test) and why.

Representation for evaluation

STUDYING THE EFFECT OF LIGHT ON THE EXPERIENCE OF SPACE IN SITU: TOWARDS A NOVEL AND INTERDISCIPLINARY METHODOLOGICAL FRAMEWORK

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Abstract

In this paper, we propose a novel methodological framework for *in situ* studies of lighting experience, combining psychophysiological measures with behavioural observations and qualitative insights.

1. Motivation, specific objective

Recent discoveries in circadian research demonstrate the multifaceted effect of light on humans yielding psychological and physiological, non-visual responses associated with circadian effects. These effects are manifested as conscious emotions and cognitive processes or even as unconscious states and behaviours. In addition, visual and non-visual effects of the light stimulus are part of a diffuse, multisensory environment, therefore, experience in space is a result of the combined effect of different sensory modalities.

The complexity of the human-light interaction reflects on the growing number of studies on the subject originating from different research domains and discourses, such as neuroscience, psychology, marketing, architecture and lighting science. However, many studies solely focus on a single aspect of light's influence on humans and only few are performed *in situ*, in the multisensory real-world, instead of the highly controlled laboratory environment. And yet, *in situ* studies are extremely useful if the research findings are meant to apply in real world and inform real practice. Therefore, there is a clear need for developing interdisciplinary collaborative methodological frameworks, extending on current research practices. Interdisciplinary *in situ* research is now being enabled by technological advances on psychophysiological monitoring, that have allowed for the production of relatively low cost mobile equipment.

To understand light in the context of space user relationship, as dictated by the need for interdisciplinary approaches in lighting research accounting for all psychological and biological, conscious and unconscious effects of light, we propose a novel methodological framework for *in situ* studies, to document both visual and non-visual responses in museum environments. Our framework combines psychophysiological measures and behavioural observations, and qualitative insights. For our research project, we use novel technologies such as mobile Electroencephalography (EEG) and Electrodermal Activity (EDA / GSR) combined with systematic observations of participant behaviours, as well as with self-reported measures from structured questionnaires or semi-structured interviews. Although the space of focus is that of museums, the methodology can be widely applied in lighting research in retail, leisure and tourism spaces, urban landscapes and other short stay spaces.

2. Methods

To study the effect of light on visitor experience, we select the Parthenon Gallery of the Acropolis Museum as a case study. The Parthenon Gallery of the Acropolis Museum, being daylit, offers a great palette of temporally and spatially dependable lighting effects as the lighting condition vary dynamically over the course of the day, wing of the gallery and the change of seasons.

Procedure: We select three lighting conditions to perform visits, during midday, evening (half an hour before sunset) and night. A total of 60 recruited paid male and female participants, split in three groups visit the Parthenon Gallery in one of the three selected lighting conditions. The apparatus is consisted of a mobile 14 channel Electroencephalography (EEG) head cap, a electrodermal activity (EDA) tracking wristband and a miniature camera. EEG electrodes are positioned according to the international 10-20 system at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4. Sampling rate of the EEG amplifier is 128Hz and of the EDA wristband is 4Hz. Each participant visits the Parthenon Gallery alone, wearing the EEG headcap and EDA wristband, while followed by the researcher wearing the miniature camera documenting overt behaviour. Following the completion of the visit, the participant takes part in a semi-structured interview in the space of the Parthenon Gallery and completes a questionnaire of the Russel and Pratt scale for environmental appraisal.

Variables: Overt behaviour is analysed to document interaction of visitors with the exhibits and time allocation. We connote “engagement”, the state, when a visitor ‘plants the feet’, stops and looks at an exhibit, or significantly slows her walking pace. When “engagement” is combined with a phasic skin coductance responses, we register an “interaction”. With the means of comparative Analysis, we compare number of “interactions” per wing (each wing has different lighting conditions) and time of visit. Comparisons of average tonic skin conductance levels, as well as the visit duration per wing are also drawn and cartographically demonstrated.

EEG measures, such as the relative power in different frequency bands, are also suggestive of visitor experience. Increate power in the frontal beta frequency band suggests a state of alertness, while alpha frequency band can be used to assess the valence of visitors’ emotion. We also analyse the verbalisation of the experience, as an indicator of thought processes and to complement our physiological data. For instance, although phasic SCR responses indicate arousal, however it is unclear whether this manifest a positive (attention, excitement) or negative (stress, fear) response.

3. Results

While this study is still on-going, initial analysis of self-reported and behavioural data suggests that there is a clear relationship between emotional experience, attention and time allocation with lighting conditions. In our study, we observe two types of behaviours: a “habitual” and a genuinely engaged behaviour. In the first case, visitors, stop and look at exhibits, however they fail to stimulate or maintain their interest. In the second scenario, visitors are intrigued cognitively and emotionally, and excited.

4. Conclusions

Observing over behaviour, for instance, where people stop and plant their feet, or allocate their time, has been extensively used in visitor studies. However, here we demonstrate that there is another aspect of experience contained within observed behaviour that could provide insights in the conscious and unconscious processes that define the experience in space. Those insights are provided by event related physiological parameters such as phasic EDA or overall indicators of cognitive state such as alpha and beta EEG waves. .

Taking research out of the laboratory and to the real world, using new tools, requires, new experimental designs, methods and techniques. However, any new methodological frameworks ought to draw on the vast and existing research and developed methodologies, in order to explore new opportunities for understanding the elusive affair of experience in space.

METHODS FOR USING IMMERSIVE VIRTUAL REALITY FOR EXPERIMENTAL STUDIES IN LIGHTING RESEARCH

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Abstract

1. Motivation and objective

Due to the growing popularity of virtual reality (VR) as a tool for conducting subjective experiments, we propose a session addressing methodological concerns and good practices for the use of VR in lighting research, going further than a simple demonstration of immersive scenes. In view of the emergence of this technology as an experimental tool in lighting studies, it is important to document and establish a reference workflow, introducing potential pitfalls and suggested practices to obtain reliable data.

We suggest a format of a hands-on workshop, where participants will be introduced to the key elements for the design and conduction of experimental studies using VR -ranging from the creation of the immersive scenes to the particularities of collecting data when the participants are immersed in a virtual environment-, coupled with demonstrations in a virtual reality headset.

2. Key elements in experimental studies using virtual reality

This section introduces the key elements for experimental studies where the visual stimulus is controlled and presented through a VR headset, categorized based on their relevance to the independent and dependent variables used in experimental lighting research, and a wider discussion about the application of this technology in lighting research.

2.1 Independent variables

In experimental studies where the stimulus is one the experimental variables, it is essential to ensure the **fidelity of the visual stimulus**. The same good practices from lighting research using other virtual representation methods, where the virtual luminous environments are generated through methods that provide accurate photometric data such as **physically based simulation** or **high dynamic range photography**, apply also for virtual reality scenes. Due to the limited luminance range of the device display, the choice and application of **tone-mapping operators** and **gamma correction** are of particular importance to ensure that the researcher has control over the scene that the participant is exposed to. Lastly, when using another software to project the immersive scene in the virtual headset, such as Unity, it is necessary to ensure that **no other light sources are present**; all lighting in the immersive scene should be derived from the photometrically accurate method of generating virtual environments that was chosen by the researcher.

Contrary to experiments using a stimulus in the real environment –such as a paper survey, or exposure to a real or virtual stimulus in the real environment-, in the case of VR the participant is fully immersed in the virtual environment. While this can greatly increase the perceived presence and realism in the virtual environment, it also introduces complexity regarding **the perception of the visual stimulus from the participant**. A notable aspect that impacts the realism of the immersive virtual scene is the **perception of depth**. This can be achieved through different **environment mapping methods** in virtual reality; for example, current advances in the Radiance lighting simulation software allow the creation of omni-directional stereoscopic content, which ensures the perception of depth for all view directions in a 360° scene**.** Other factors that can negatively affect the participant's perception of the virtual stimulus is the **usability of the immersive virtual environment**, which could cause **motion sickness** and can be minimized through choices regarding the content and quality of the presented scenes. Similarly, **external stimuli** such as noise and temperature can influence the perception of the virtual scene, and should be monitored and controlled to a comfortable range during the experimental session.

2.2 Dependent variables

The collection of **subjective evaluations** from the participants presents some particularities in virtual reality. Since participants are immersed in a virtual environment, they cannot interact with a physical questionnaire. An alternative is a **verbal questionnaire**, where the researcher asks the questions, introduces the rating scale, and records the participant's responses. In the authors' studies using a verbal questionnaire, **simpler rating scales with intuitive ranges** (such as 1 to 5, or 1 to 10) were preferred to more frequently used ones (such as 1 to 7). Similarly, participants preferred to use **numbers rather than verbal qualifiers** (such as 'slightly', 'moderately', 'very') to evaluate the stimulus when they did not have a visual reference of the rating scale. Another solution is the use of **visual references**; either through an interactive questionnaire, or a visual representation of the verbal questionnaire, shown in VR. However, this solution affects the reliability of **head-tracking data** -where participants looked towards in VR-, as they will react to the presented question along with the virtual scene.

The immersion of the participant in virtual reality also greatly facilitates the collection of **physiological measurements**. In addition to the participant's head movements, which can be obtained from the VR headset, devices measuring physiological indices such as skin conductance or electroencephalography data can be used, as the time of exposure to the stimulus in VR can be recorded with a very high precision. It is however is essential to ensure the **synchronization of collected data with the exposure to the visual stimuli**.

2.3 Applications and limitations of VR as an experimental tool in lighting studies

Recent studies have shown the validity of virtual reality as both an educational and an experimental tool to investigate the perception of luminous environments, highlighting the potential of this technology for lighting research. However, the limited luminance range of current VR headsets does not allow the creation of conditions that can induce discomfort. Moreover, further work is needed to investigate the effect of color and level of detail on the realism of the virtual environment in VR.

3. Outcome

The proposed workshop aims to provide a reference for the development and conduction of experimental studies using VR in lighting research, coupled with a hands-on experience of immersive virtual scenes. Furthermore, it will introduce and address methodological concerns for the use of VR in research, covering the key elements related to the experimental variables and the limitations of this technology. The length of the proposed workshop can be discussed and adjusted according to the interest and schedule of the CIE Expert Tutorial and Workshop.

BENEFITS OF BRINGING THE REAL WORLD TO THE LAB: INVESTIGATING LIGHTING BEHAVIOUR IN HOMES USING A FULL-SCALE MODEL

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Abstract

1. Motivation, specific objective

To evaluate the first prototype of a home lighting system, we used a full-scale model of a studio apartment in the laboratory of the School of Architecture at Lund University. The personalised home lighting system is based on LEDs, wearable sensors and a mobile phone app to produce lighting tailored to the individual's needs. Drawing on participant interviews (n = 28), which were held in the full-scale model, this paper seeks to highlight the benefits of using a three-dimensional representation at full-scale.

Studying real-world problems that involve people's behaviour do not always allow research in their natural environment. Investigators must therefore choose other methods. One option is to use a two-dimensional visual representation of the real-world environment, e.g. photography prints or static or dynamic visual simulations on a flat screen. A second option is a 3D-simulation with special glasses. A third is to create the desired environment using either small-scale or full-scale models. Each approach has merits and limitations but, in lighting research, the effects produced by lighting, such as visual comfort, must be considered. The lighting situation is always influenced by the light source and the luminaire, the surfaces of the space reflecting the light, and the observer perceiving the light (individual characteristics and previous experiences). Neuroimaging studies have found that sensorimotor systems are engaged when humans experience the environment around them, and when viewing images or other people. Both mind and body can be activated, e.g. emotions and facial expressions. However, images have several limitations. Firstly, images projected on modern screens cannot produce glare, which makes evaluating simulated lighting situations difficult. Secondly, flat images cannot capture well enough how lighting is influenced by spatial and surface characteristics. Thirdly, 2D-simulations or photographs on a flat screen do not enable a full mind-body experience since physical movement within the space is not possible.

2. Methods

Both quantitative and qualitative data were collected during April and May 2016 using a convenience sample (n = 28, 50% female, median 41 yr). Each participant was engaged for a 24-hour trial in the field and for one hour in the lab. On the first day, the participant received the wearable sensors, which measured light exposure and rest and activity patterns. After 24 hours the participant returned to the lab and was given a demonstration of the new home lighting system in a full-scale model of a studio apartment (floor area 38 m2). A small self-service breakfast buffet was included in the 'kitchen'. The participant completed a questionnaire addressing the comfort of wearing the sensors and the participant's willingness to use the home lighting system in the future. To cross-check the assessment and to provide supplementary information, the trial ended with a structured interview with open-ended questions, lasting 10-30 minutes. The interview questions addressed lighting behaviour in the participant's home: which lights were turned on in the morning and evening (including digital screens), the use of daylight and shade, and the darkening of the bedroom at night. The interview involved the participant giving a detailed description of the home environment. The interviews were analysed thematically to provide a deeper understanding of factors influencing their willingness to use the home lighting system or not. Additional themes were the lighting vocabulary used by participants, the effect of available daylight on participants' use of electric light, and methodological insights.

3. Results

The results relevant to this paper concern the methodological insights. The physical setting, where the interview took place, enabled participants to describe better their home environment. Eleven

participants made comments comparing their own home characteristics and those of the full-scale model in terms of:

- room layout and furnishing,
- size of window openings,
- participant-designed blackout screens in the bedroom,
- thickness, transparency or colour of curtain fabrics,
- type of luminaire: floor-standing or ceiling mounted,
- size of luminaires,
- placement of floor-standing luminaires,
- design of floor-standing luminaires,
- colour tone of lamps (cooler or warmer, bluish or yellowish).

Participants who gave poor descriptions of their home environment were encouraged to compare to the objects and materials in the full-scale setting.

An unexpected benefit of the physical setting was the less formal atmosphere created by the homelike appearance of the full-scale model. It is reasonable to assume that interviews conducted in a homelike environment, seated on a sofa or an armchair, might make participants more relaxed. Participants were surprisingly open about their everyday behaviours, e.g. sleep habits, clothing or no clothing at night.

4. Discussion and conclusions

As several participants, unrequested, used objects or materials in the full-scale model for comparison when describing features of their own home, it is suggested that a three-dimensional representation at full-scale might elicit more information from the participants. Even though the setting does not fully correspond to a residential environment, there are differences between looking at a place and being in a place. In participants' appraisal of a place, lack of colours and textures, on the walls and the ceiling, is not necessarily a problem.

Previous research studies used systematic evaluations of 2D- and 3D-simulations, and real settings. A Swedish study investigated participants' assessment of four different car interiors, both real cars and photographs on a computer screen using the Semantic Environment Description method. Results showed that the evaluation between the real situation and the visual representation differed in terms of 'unity', 'complexity', and 'enclosedness'. A more recent Swedish study, exploring the reliability of colour and light appearance in 3D-models, showed that colour variations and shadows in renderings have improved, but contrast effects and inter-reflections between angled surfaces are still incorrectly represented.

To illustrate the limitations of images on a flat screen, watching a movie at the cinema may serve as an example. Movie scenes on a large screen can evoke strong sensations, for example, sudden noises. But have you ever been blinded by, for example, the sun in a science-fiction movie?

A CRITICAL ASSESSMENT OF THE USE OF CALIBRATED PHOTOREALISTIC IMAGES FOR VISUAL EXPERIMENTATION IN LIGHTING

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Abstract

We have been using calibrated high resolution images for more than 20 years as part of experiments on vision and lighting. Progress in display technology has been significant in the last 10 years, which make this approach particularly attractive. However, there is a number of practical aspects which should be taken into account to guarantee the success of the experiments. On top of this, it appears that the narrative of the test should be carefully elaborated to define the most appropriate stimuli in relation to the questions asked to the observers. This is essential to ensure that the answers they provide are in line with their exact emotional, cognitive and sensorial conditions.

1. Motivation, specific objective

Panels of observers are currently being used to rate or compare lighting schemes. This is usually conducted either in laboratory, or on site with specific and controlled conditions. In the case of comparison of visual stimuli, this creates a significant challenge to build a number of lighting options and to find a way to present them to assessors without interferences of the lighting solutions between themselves. For examples luminaires which are not used are still visible. Also, these types of experience limits the investigation to lighting schemes which we can supply, since it is not possible to test new concepts at the design stage.

Hence the growing interest for using calibrated photorealistic image display in experimentation in the field of light and vision..

Technology of image display has progressed over the last 20 years. In 2018, it is no more a luxury to produce and display high resolution images using formats such as Full HD (1 080 x 1 920 pixels) or 4K (4 096 × 2 160 pixels)

Images can be supplied from photographs using high resolution, and High Dynamic Range (HDR) cameras, or generated by computer with a number of software with good level of validation in the domain of optics, light propagation and material simulation.

With such procedures, it is possible to produce images with information of luminance, and colour coordinates for each pixel. These images need then to be shown to panels of observers in conditions suitable for the testing sessions.

Such images appear particularly convenient to present, in comfortable conditions, lighting options of given spaces to panel of observers.

Since 1999, we have been using high resolution images to explore lighting schemes, both concerning electrical lighting and daylighting, and both with photographs and computer generated images. In 1998, we were using projected images with luminance typically in the range of 0 to 300 cd/m2, and since 2013, we used equipment able to reach higher luminances, above 500 cd/m2 and even 20 000 cd/m2 for glare assessment with powerful video projectors.

We would like in this paper to bring a number of issues which we learned over the last 20 years of experimentation, concerning the various options in methodology which can be used with this technique

2. Methods

A number of methods were developed to produce information, or to develop metrics, concerning luminous environment and lighting installations. This was done through testing sessions using panels of observers looking at photorealistic images and videos. They were either observing in groups, or alone.

- Method 1: observers are presented fixed images or videos, and must rate them on specific scale (attributes could be agreeableness, comfort, interest, warmth, etc.)
- Method 2: observers are presented image by pairs and must discriminate them, being driven by specific questions.
- Method 3: observers are asked to compare images or videos (visual stimuli) by pairs, and must answer a given question. They do so in selecting which of the two scene provides, according to their opinion, the best answer to the question (attributes are preference, suitability, fear, content, cosiness, status, etc.)
- Method 4: self adjustment: in this case the test must be individual, and the observer can adjust light power or colour of specific lighting channels and propose the best answer, to his/her view, to the question which was asked.

3. Results

Conditions of tests: we have found that such tests could be tedious, and it is important to limit the duration of testing in 10-15 minute sub-sessions. With 5 minutes breaks between sub-session, and the maximum duration of the entire session should no exceed 45 minutes. It is also the responsibility of the organizer to assure that the observers are motivated. Everything should be made to make the experience enjoyable (think at wine testing!). All session should begin with a exercise, to verify that all observers fully understand the procedure of the experiment. It is a moment where they can ask all questions. For all tests, we always have tested the procedure among ourselves first to see if there was some details to improve. For all tests, we repeated some trials to check if observers were consistent in their response, between the beginning and the end of the session. One danger if the preliminary training is too short, is that observers take some time to provide reliable answers. For some cases, we even rapidly browsed through the stimuli beforehand, so that the observers have an idea of the spectrum of the stimuli which were going to be presented.

For self adjustment, we found that multichannel control should not exceed two channels, since observers found 3 channel control hard to adjust.

Concerning the realism of the images, some rendering algorithms were considered more realistic than others. Stereographic display was found appropriate for improving understanding of scenes in indoor lighting, although it did not lead to different results in comparison with mono projections. Size of images matter, with a preference for image width between 0.5 and 1 times the viewing distance. Large size image were found more realistic (with higher than 2,5 metres). Surface in projection room were considered as more adapted if not black (light grey) to reduce visual stress and provide a kind of adaptation of luminance. Format of images had to be adapted to the topic: for some interior spaces, we used images with a width larger that two times the height.

4. Conclusions

After 20 years of experimentation, we found that a key concern is the psychological state of the observers during the test. Not only he questions which are asked should be fully understood, but the content of the images fully in line with the emotional and sensorial readiness of the observers. For this reason, we increased the realism of scenes in adding content, facilitating judgement, and linking to the precise use of the space to evaluate a kindergarten room is not an office room, which is not an apartment, a hotel room, or a lounge. We added video experiments and even sound track to improve the experience level. Since 2012 we have used head Mounted Displays for conducting tests, and we found that this immersive equipment is very appropriate to provide answers to question where geometry is essential, but quality of screens were found insufficient for sensorial assessment.

Posters

CHROMATIC ADAPTATION DEPENDENT COLOUR DISCRIMINATION OF COLOUR NORMAL OBSERVERS

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Abstract

1. Motivation, specific objective

The objective of our study was to examine changes in chromatic discrimination abilities of colour normal observers in the function of adaptation chromaticity.

2. Methods

In the study colour normal observers performed the trivector test of the Cambridge Colour Test in order to measure the just noticeable stimuli on the three confusion lines. Reference chromaticities were equidistant points towards 8 directions equally spaced and centred on the neutral point in the CIE 1976 UCS diagram covering the gamut of a CRT display.

Subjects accomplished different parts of the experiment, with 20 subjects performing the test in each reference point. The average age of the subjects was 22,8 (±1,4) years.

Results were evaluated in the function of the background chromaticity.

The factors (and their levels) of the statistical analysis were the analysed confusion lines (Protan, Deutan and Tritan), and background chromaticities (distance and direction from the neutral point).

3. Results

The analysis shows that the results in the function of distance from the neutral point towards the Protan and the Deutan confusion points correlate in each directon.

Discrimination thresholds increase, hence chromatic discrimination ability decreases towards the confusion points while the background colours are shifted towards the direction of measurement. However if the background colour is shifted in a direction away from the confusion lines thresholds do not show significant changes.

4. Conclusions

Chromatic discrimination of colour normals is more affected by the adaptation chromaticity towards the confusion points.

LED QUALITY EVALUATION BY OCULAR FUNCTION AND MENTAL LOAD

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Abstract

1. Motivation, specific objective

LED luminaire brings about a brighter environment for human beings. As a special kind of self-adaption optical system, human eye remains immersed in the lighting environment during the daily life. During the image forming in the retina, the eye adjusts itself in structure and function for the acquisition of clear image in high quality. The adjusting ability varies during the working process as the change of lighting parameters such as illuminance and correlated color temperature. Consequently, the ocular function tends to alter in different degrees. During the work in various lighting environments, mental load including psychology stress and information dealing ability is also likely to be accumulated in different levels. The combination of the ocular function and mental load reflect the influence of the lighting environment. Eye fatigue is likely to emerge in the ocular optical system, while mental fatigue is likely to emerge in the cortex which is responsible to information dealing process. The eye fatigue describes the visual fatigue in view of objective ocular function, and the mental fatigue describes the visual fatigue in view of mental perception. By the construction of the relation between LED quality and ocular function as well as mental load, it is expected to figure out the proper lighting parameters for visual health and to improve the working efficiency. In the lighting environment with the proper lighting parameters, the visual fatigue caused by ocular adjusting in the respective lighting environment is likely to be reduced to the minimum value. This is important to the design of luminaires in the healthy direction. In this study, LED lighting parameter is the first time to be related to human physiology parameters.

2. Methods

Ocular function is described by a series of physiology parameters including the keratometric refractive, axis length, pupil size, aterior chamber depth, lens thickness, accommodative convergence to the accommodation, high order aberration, modulation transfer function, intraocular pressure, and breakup time of tear film. Mental load disturbs the thinking process, thus slowing down the reaction. In the present study, we select five physiology parameters to represent the ocular function status: keratometric refractive, axis length, accommodative convergence to the accommodation, high order aberration, and modulation transfer function. Other parameters are excluded due to the instability and difficulty in the implement. For the measurement of mental load, we use reaction time, heart rate and EEG methods. Before the experiment, subjects were allowed enough time to relax their eyes. Then the five ocular function parameters, reaction time, heart rate and EEG signal were collected. After that, subjects were asked to finish the visual task (Landolt rings counting and screen watching) in different lighting quality parameters for 45 minutes. Then the five ocular function parameters, reaction time, heart rate and EEG signal were collected again. Among all data, the five ocular function parameters were transported to the machine learning algorithm model as the input layer, and the output layer were calculated in the form of VICO value which is used to assess the LED lighting influence on ocular function. In the current study, the machine learning algorithm is selected as back propagation artificial neural network (BP-ANN) due to its high speed and simple form. Reaction time, heart rate and four types of brain waves in EEG are employed to describe the mental load. The measurement illuminances distribute in the range 200 ~ 700 lux and the correlated color temperatures vary from 3000K to 6500K. Psychology questionnaire is also utilized as an auxiliary.

3. Results

Correlation analysis is carried out between lighting quality parameters (illuminance and correlated color temperature) and ocular function parameters as well as mental load indicator parameters (Reaction time, heart rate and EEG signal. Correlation with significance emerge between illuminance and ocular function parameters, as well as between correlated color temperature and mental load indicator parameters. In the lighting environment with the illuminance of 550 lux, all selected ocular

function parameters present the least variations, and the VICO value reaches the minimum value. In the correlated color temperature of 5000K, reaction time and heart rate are subject to the least influence. For EEG signal, the signal activities decrease little in frontal region compared to other correlated color temperatures, and $(\alpha + \beta) / (\theta + \delta)$ present the maximum value. Subjective scores show correlation with the results based on physiology parameters, but the correlation is not high enough. This may result from the instability and fluctuation of subjective perception.

4. Conclusions

Traditional research tends to simply use subjective scoring to describe the luminaire lighting quality, making the evaluation instable and inaccurate. In the current study, we separate the fatigue perception into the ocular function part and the mental load part. By the correlation construction between lighting parameters and physiology parameters, we figure out the proper illuminance as 550 lux and the proper correlated color temperature as 5000K. It is the first time that objective physiology parameters are used to evaluate the lighting quality of LED luminaire.

AN EXPLORATION OF HUMAN CENTRIC LIGHTING EFFECTS USING A CASE STUDY APPROACH

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Abstract

The motivation for this case study has developed out of the significant research around human centric lighting and the effect it has on human health and well-being. Specifically, the relationship between how much, and the quality of light you get during the day and variables such as lighting appraisal and room appearance; mood including work focus and creativity; environmental satisfaction; and subsequent resulting overall health factors. Both self-reported qualitative health benefit descriptors, and more recently quantified psycho and physiological health benefits towards the alleviation of Depression; Post Traumatic Stress and Alzheimer's trajectories through modifications to serotonin and melatonin levels, have been presented in current human centric lighting research.

One gap in this research is an investigation of whether there is a relationship, and the form of the relationship, between the amount of time exposed per day to human centric lighting, and number of hours of sleep at night, as well as other self-reported variables such as office visibility; physical activity; social communication; mood-comfort; work focus; and stress level. Further, an investigation of the cumulative, longitudinal relationship between the amount of human centric light exposure and heart rate trends at two time specific measurements during the day.

Nano-Lit Technologies is a human centric quantum dot lighting company whose first product offering is the Smart Diffuser.™ It is both an aftermarket retrofit and a new product that will fully replace fluorescent tubes in workplace lighting. The product's key attributes are: ability to simulate sunlight by shifting colour temperature from 2700K - 7000K throughout the day and the capacity to automatically tune lighting output by using nano-engineered Quantum Dot technology. Nano-Lit Technologies currently has sixteen TRL 7 Smart Diffuser™ prototypes designed for fit, form, and function for office environments as part of a BETA demonstration at a Canadian location that at this time will remain private. They are installed in two separate spaces: Interior meeting room (no direct sunlight) and an interior office (no direct sunlight).

A longitudinal case study is being carried out at the above mentioned location to provide insights into the research questions posed above. This case study is defined as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context. It relies both on qualitative and quantitative evidence and benefits from the prior development of theoretical propositions. The data collection period will be six months, after which time exploratory data analysis will begin. The investigation of statistically significant relationships will aid in the formulation of hypotheses for further research studies. The authors will pay significant attention to confounding variables when investigating possible relationships. The outcome of the case study is to gain a sharpened understanding of possible relationships, and what might become important to look at more extensively in future research, rather than making any definitive claims about light exposure and cumulative human health effects from the specific case study project.

HUMAN-CENTRIC TOOLS FOR VISUAL COMFORT ASSESEMENT

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Abstract

1. Motivation, specific objective

Providing comfortable, healthy buildings with high energy efficiency is a key challenge for the future. Solutions that combine both safety and comfort for the occupants with sustainable approaches to address the environmental challenges have to be implemented in construction field. In this frame, new methodologies to assess the comfort of occupants have to be developed to help the understanding of comfort definition and the development of innovative solutions that improve comfort.

Regarding visual comfort, the positive impact of natural light on people health and wellbeing is largely demonstrated. However, if daylight is increasingly highlighted in new construction, it still represents a largely unexploited resource in existing buildings for saving energy and improving occupant's comfort.

In this context, there is a need for extensive evaluation of the comfort, based on metrics and non-intrusive diagnostic but also on human experience and perceptions. This is why we developed new tools that are described in this paper.

2. Methods

Our work is focused on the development of indicators of comfort and on setting up the associated evaluation protocols to bring scientific evidence that a building is reaching the expected comfort target. A set of tools presented and discussed below has been developed to quantitatively assess visual comfort in existing places. Non-expert users and trained staff have the possibility to access the quantification of their comfort. The tools combined together aim at providing non-intrusive and quick assessment of occupied spaces.

Survey tool:

By combining physics with sociologic field, thanks to the help of Sociologists, we focused on a human-centric approach to develop a questionnaire, including all aspects of visual comfort. Our four main indicators to define visual comfort are natural light, artificial light, views (outside and inside), and quality of interior space. The survey is actually developed for offices evaluation, with an occupant questionnaire and an expert questionnaire. All steps were calibrated thanks to the collaboration with occupants, using in-depth sociologic interviews in some reference offices. Grades for our 4 indicators can be calculated from the answers. The result is then crosschecked with occupant perception. This global and human centric evaluation can come with additional annual simulation, to quantify daylighting assessment of the room.

Simulation tool:

Simulations are usually performed using professional software dedicated to trained engineers or daylighting experts. In this frame, there is a lack of an easy-to-use simulation tool to quickly diagnosis the daylighting metrics in a space. We developed therefore a quantitative simulation application that can be used directly by the occupant or a non-specialist in a few minutes on a tablet. This application relies on Radiance free software library for ray tracing and daylighting simulation. The tool was tested and validated with DIVA software. This fast annual simulation tool associated with the occupant survey presented above provide a global evaluation of visual comfort in an occupied space with non-intrusive methods. Experimental measurement is valuable to follow-up diagnostic on mid to long term periods, and to validate the expected performances.

Experimental evaluation tool:

Measurements in buildings are nowadays not common. Measurement tools already exist but are usually complex, intrusive and can only be handled by experts. To easily perform measurement, we

developed a wireless and low-cost setup for illuminance measurements which, due to its small footprint and ease of installation, is particularly suitable for occupied offices. One objective of such a tool is for example to perform a quantitative diagnosis during renovation. A quantitative diagnosis is a necessary step for comfort assessment in new and existing buildings. The experimental setup protocol has been developed for both short and medium term measurements of illuminance. The setup was validated through comparison with professional wired luxmeter.

3. Results

The tools we developed are complementary and the result of visual comfort diagnosis is particularly useful to forecast discomfort areas and fuel a discussion around possible technical solutions to improve visual comfort. The tools were already used in case study to compare visual comfort before and after the renovation of offices in Switzerland.

Evaluation of building with tools that include the occupants is also a way to raise awareness about visual comfort and daylighting. But it can also be a way to listen to the occupant's need. As an example, key finding extrapolated from the interviews to create the questionnaire highlights that a relevant part of comfort is customization: the possibility to choose and the possibility to control.

Feedbacks are valuable to understand the technical limitations and the need of the users. Regarding experimental evaluation, the critical question lies on the proposed protocol, and the duration and complexity of measurement to obtain a reliable evaluation. In addition, the measurement data processing in occupied spaces is often complex due to the use of shading devices, of artificial light, or of shadowing provoked by occupant activities. Regarding the simulation tool, efforts for further improvements are focused on the user friendliness and output presentations. On the questionnaire, the comparison between expert quantification of comfort and occupant perception of his own comfort shows mismatch in some cases. Indeed, quantification of human perception is also a complex procedure and a work is ongoing to improve this aspect.

4. Conclusions

The evaluation of visual comfort is performed through internally developed tools that are measurements and simulation of daylighting performances in a room associated to an occupant satisfaction survey. The tools are evolving; they are used and deployed internally to collect feedbacks on the protocols and the data. In order to raise awareness of visual comfort, we propose educational tools that can be implemented by non-experts with a scientific background. For this, collecting the academic feed-back on the tools and methodologies is absolutely key.

BIG DATA FOR DAYLIGHT ANALYSIS: CHANCES AND CHALLENGES

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Abstract

1. Motivation

Most light-driven processes, as for example non-image forming (NIF) effects, are spectrally selective and can be described by action spectra. An action spectrum reflects the wavelength dependency of the sensitivity characterizing what wavelengths elicit a specific response. While it is widely common to quantify the spectral sensitivity for NIF effects with an action spectrum peaking near 490 nm, the spectral effectiveness during daytime and thereof the daytime responses elicit by daylight are still largely unknown. Thus, to properly simulate or evaluate daytime NIF responses in the future, we need spectrally resolved information on daylight, which is orientation specific. One of the aims of the presented work is the development of data-driven spectral sky models which provide orientation dependent spectral characteristics of daylight in simulations.

2. Methods

Spatially and temporally resolved spectral sky measurements, that have been carried out since October 2014 at the XXX, are being used for this purpose. Every second minute during daytime, a sky scanner measures the spectral power distribution (SPD), between 280 nm and 980 nm, of light from 145 sky patches distributed over the entire sky-dome. Up until now, this resulted into over 40 million daylight spectra, and the measuring process is still ongoing.

3. Conclusions

The big data approach brings along new chances but at the same time entails considerable challenges. On the one hand the large amount, the ever-increasing volumes and the variety of the data-sets provide more information and thereof result in new opportunities for daylight analysis. To name a few, the big data approach:

- allows a more precise predictive and descriptive data mining, e.g. to develop standardized spectral skies for data-driven modelling,
- paves the way to a conclusive approach to validate correlations and patterns between multiple streams of data, e.g. to support a data-driven lighting management by linking results in near-real time of spectral daylight data with human response models, and
- enables a better review of existing analytic approaches, e.g. the verification of SPD reconstruction from correlated colour temperature.

On the other hand, data management is becoming increasingly complex, what generates various challenges, e.g. the analysis and representation of data streams require database systems, programming skills, specialized data analysis tools and sophisticated data cleansing workflows. Therefore, to translate large data-sets of daylight measurements into smart data for NIF simulations, new tools and methodologies are need. The poster presentation will touch upon the chances and challenges of big data in daylighting studies for NIF with practical references.

BLUR ACCEPTABILITY THRESHOLD IN OPTIMISED LIGHT PROJECTION SYSTEMS

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Abstract

Light incident on the surface of an object contributes to visibility only when it is reflected. Light absorbed by an object turns into heat and can be considered loss. Since it is possible to control the spectral output of the solid-state lighting (SSL) devices, we can conceive of a smart lighting system that detects surface colour of objects and emits spectrally-tuned light for each object, to reduce energy consumption by minimising absorption. Such a lighting system could estimate surface spectral reflectance functions through sensors and project optimised spectral power distributions (SPDs) precisely onto individual objects.

Previous studies show that theoretical SPDs optimised for object reflectance can result in energy savings, without causing perceptible colour shifts. Observers have found real objects to appear equally natural and attractive, when illuminated by optimised narrowband LEDs than when lit by reference white sources (phosphor-coated LEDs). Data from these experiments also underlined the potential to increase energy savings by enhancing object chroma. However, previous absorption-minimisation studies only considered objects of a single hue. Since, in real life, most objects have varying degrees of complexity in term of colour appearance, a projection system would be required to emit optimised light with spatial precision. This study aims to investigate the spatial resolution of the optimised lighting system by quantifying visual perception of blur.

Methods

A visual experiment is designed to investigate blur perception as a function of the optical defocus of projected light. A liquid crystal on silicon (LCoS) projector will be used to illuminate three paintings that have varying degrees of spatial complexity. Spatial perceptual information (SI), a standardised method for measuring the spatial detail of images (ITU-T, 2008), will be used to quantify the complexity of paintings. Images with low complexity (Piet Mondrian's 'Composition A,' SI = 34.5), medium complexity (Grant Wood's 'American Gothic,' SI = 45.6), and high complexity (Pieter Bruegel the Elder's 'Netherlandish Proverbs,' SI = 54.8) were chosen as test pictures.

A digital image of each test picture will be projected onto a printed version of the test picture, positioned 1.65 m from the projector. Preferred viewing distance (PVD = 4.3 m) was calculated using International Telecommunication Union (ITU) recommendations (ITU-R, 2012). Instead of a painting on canvas, printouts of digital image will be used to reduce size and colour differences between the physical and the digital images. Although the projector will be positioned next to the observer, resulting in a triangular setting, this is not expected to impact blur sensitivity due to the dioptrically symmetric nature of two-dimensional blur perception.

The experiment will consist of three sessions. In each session, a single test picture will be presented. For each test picture, five defocus conditions will be created by adjusting the focal length of the projector lens. One of the focal length settings is the reference setting, where the image is perfectly focused on the printed picture. In the other test conditions, the projected image will be blurred by changing the focal length of the lens between 0.25 dioptre and 1.0 dioptres. Each defocus condition will be presented ten times in a pseudo-randomised sequence for each session, to minimize bias. As a result, there will be 5 x 10 = 50 trials within each session. Although each judgment will be restricted to four minutes to prevent adaptation to blur, observers are expected to make judgments more quickly than that.

A minimum of 15 non-expert observers will participate in the experiment. Prior to the experiments, observers will be tested for visual acuity using a Snellen chart and for colour vision using pseudo-isochromatic Ishihara plates, and they will be carefully introduced to the method of assessment. Observers will be asked to judge their impression of the clarity of the painting using a mean opinion score (MOS) scale, ranging between 1 and 5. A score of 5 denotes 'excellent' quality with 'imperceptible' impairment, while a score of 1 is 'bad' in quality and 'very annoying' in terms of

impairment. The middle value, a score of 3, is 'fair' in quality and 'slightly annoying' in terms of impairment. In the training sequences, a picture similar to the test pictures will be shown to participants to demonstrate the type of impairments to be assessed and reduce central tendency bias, by encouraging participants to use the full range of the MOS scale.

In a previous subjective blur assessment study, researchers have found a jump between MOS scores of 2 and 3.5, which suggests a blur detection threshold (Crete et al., 2007). In contrast, the experiment planned here is not designed to quantify an absolute blur detection threshold. However, data from this experiment are expected to indicate a statistical measurement of two-dimensional blur acceptability. The results will be analysed using the mean, standard variation and 95% confidence intervals of the statistical distribution of the MOS scores, and non-parametric statistical tests (e.g. Mann-Whitney U test).

COMPARISON OF SENSORY AND EMOTIONAL EXPERIENCE OF LIGHT IN SPATIAL CONTEXTS

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Abstract

Introduction

Man is guided by biological, physiological and sensory functions and is at the same time a social and cultural creature, who also has specific needs and preferences at the individual level. It is in fact not possible to separate these aspects if the goal is to create a basis for good light environments, and therefore a definition of light quality needs anchoring in all of these levels.

The paper presents two pilot studies conducted as part of an ongoing multidisciplinary research project. The overall objective is to develop definitions and a concept model for light quality, based on visual/sensory and emotional experience of light. The results of the studies are compared, one of which (Study 1) aimed at validating a collection of concepts for perceived light qualities, and the second study (Study 2) aimed at investigating the emotional experience of different light environments. Both studies were conducted with scale models with identical furnishing, and were on both occasions illuminated with fibre optics or LED strips.

Methods and experimental design

The basis for Study 1 was a typology for light environments where different parameters for light distribution and colour contrast were combined. Three different principles for lighting at various light levels were combined with colour settings with three different degrees of achromatic contrast. The typology illustrates 81 different combinations and serves as a reference to illustrate how light and colour can either interact or counteract the visual perception of space. Before the study, scale models were built based on six examples based on typology. Prior to the study, six scale models were built based on examples from typology.

A couple of models represented extremes, such as very dark or bright environments, while some other models were identical but had different lighting or colour contrast range. 17 subjects of different ages participated in the study. A collection of concepts for light character developed through project workshops was selected for the study. They were divided into three categories: overall experience of the room, experience of light and experience of shadows and assessed with semantic differential scales in each model. The subjects were also asked to assess if they considered that the light environment in each model was appealing or not, as well as suggesting an appropriate type of activity or function for the environments. Study 2 was conducted as a workshop on the theme of emotional experience of light. The purpose was to collect concepts as a basis for future studies in the same way as concepts for visual / sensory experience of light have been gathered earlier. As in Study 1, scale models, LED srips and fibre optics were used. The big difference was that chromatic colours were used and that lighting and colour schemes were made based on specific design concepts to consciously create different atmospheres. The 19 participants assessed the atmosphere of each model by spontaneously describing them with words written down on post its. When all the light environments were assessed, the lighting was replaced by simply changing the light between different models. The purpose was to investigate to what extent and in which way the new combination of light and colour would affect the atmosphere.

Results and discussion

An assumption that was made before study 1 was carried out was that several of the words assessed in the study would prove to be synonymous. However, the result showed that similar words were used to describe different shades of light characters. An example is the assessment of two models with identical, even light distribution but different colour contrast. In one model, the participants described the light as monotonous, but in the other as even. Another finding was that contrast richness seems to be more important than light level for a room to be perceived as legible.

Interestingly, a room with high colour contrast and even light was perceived as clear as a room with varied lighting and low colour contrast. The compilation of the subjects' suggestions for functions for each light environment showed that both the light distribution and the colour scheme determine the experience of the light environment. Two completely white models with different lighting (even and varied) gave a completely different impression. One model was associated with, for example, an operating theatre, school or office, while the other was associated with a living room, kitchen or a shop.

Study 2 generated similar conclusions about the importance of light and colour interacting for the emotional experience of an environment. In the first round, the participants associations was mostly corresponding with the design concept. A reflection of the results is that it was surprisingly easy to create the intended associations despite very simple materials. The second round, when the light was replaced, created confusion and the environments became difficult-to-understand. For example, a model that was experienced as cosy and a bit mysterious as it had both subdued light and dark red colouring, was perceived as desolate and even awkward in the second round. Another model with bright walls and details in bright colours was perceived as energizing and summery in the first round, became uninspired and unnatural in the second round.

A comparison of the results of the two studies is possible because the models used are the same, and also the principles of lighting. What can make a comparison interesting is if it turns out possible to identify specific visual light qualities that also affect the emotional experience. If concepts can be correlated to specific character for light and shadow, it would be possible to create a basis for a concept model, which then can be used as the starting point for making conscious choices for both the visual and emotional perception of environments.

As the project is ongoing, it is not possible to present any final conclusions in the paper. The intention is primarily to open up a discussion about the possibilities and benefits of the concept model and to gain new approaches.

A HOLISTIC FRAMEWORK OF POST-OCCUPANCY EVALUATION FOR ASSESSING ADAPTIVE BEHAVIOUR OF USERS IN THE LUMINOUS ENVIRONMENT

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Abstract

1. Motivation, specific objective

The relation between light, space and user is multifaceted containing quantitative and qualitative aspects of light. That is why, evaluation of luminous environment can be achieved holistically when the quantitative and qualitative aspects of light are evaluated as a whole within the spatial context of the user. The quantitative aspects of the luminous environment can be predicted through the guidance of the lighting metrics. On the contrary, the qualitative aspects have been less included in the lighting regulations, research and building evaluations.

In addition to the design decision-making process of the new buildings, assessment of the luminous environment of the existing buildings is significant as well. It is noteworthy to underline post-occupancy evaluation (POE) methodology as it probes how an indoor environment performs and how satisfied the users are when occupying a building. The evaluation of lighting has been often integrated into the studies appraising the indoor environmental quality (IEQ) and POE of the overall building circumstances. Forming a distinct evaluation procedure on lighting can supply the practical base required for combining the quantitative and qualitative assessments of the luminous environments in the existing buildings.

Adaptive behaviour has been underlined in literature as containing significant actions of occupants in order to enhance their comfort. While most research on adaptive behaviour focused on thermal comfort, a recent study underline how adaptive behaviours had a positive impact on visual comfort.

The main aim of this on-going PhD research is to propose a holistic framework of POE for assessing the adaptive behaviours of users and the appraisal of lighting in the luminous environment. Through the proposed framework, this research intends to investigate the relation between light, space and user through guidance of the qualitative and quantitative assessments of the luminous environment. Determining the positive and negative aspects of the lighting-related measures on space and user is informative in order to carry out the related amendments and enhancements in the luminous environment.

The research problems and limitations, which have been identified in the literature review, mainly underlined the discrete evaluation of the luminous environment and the integration of the adaptive behaviour for visual comfort as the limited research topics. That is why; this research proposes a POE framework, which aims to create a holistic and robust evaluation of lighting through;

- integrating space, user and task related parameters into the evaluation of lighting,
- exploring the alliance between occupant's use of a space, perception of the space and experience of the lighting system,
- integrating adaptive behaviour of occupants, which aims to improve visual comfort and satisfaction, into the POE process.

2. Methods

A recent study of Veitch et al. (2013) identified the relations between lighting appraisal, workplace satisfaction and work engagement. The lighting appraisal affected room appearance, which influenced pleasure. The lighting appraisal and the room appearance affected workplace satisfaction. The workplace satisfaction had impact on environmental satisfaction and self assessed productivity. The authors worked on an experimental study. Following this, they utilized structural equation modelling (SEM) in order to finalize the model they proposed and evidence the relations between the above-mentioned variables.

The literature review of this PhD research found out that interior design and furniture layout were parameters affecting the comfort of occupants. It is also seen that occupants benefited from the flexibility in their spaces to improve their comfort. This adaptability; in other words, adaptive behaviour as part of occupant behaviour is a noteworthy parameter as it has the potential to enhance comfort. As glare depends on the occupant position, direction of view and perception of light is affected by the field of view, the adaptive behaviour of occupants is expected to affect both visual comfort and perception of light.

In this research, final SEM model by Veitch et al. (2013) has been evaluated as the original model and extended for proposing the SEM model of this research. In the proposed SEM model, adaptive behaviour for lighting has been considered as a latent variable. The four variables, which constitute adaptive behaviour for lighting, have been determined as furniture position and orientation, occupant position and orientation, colour of internal surfaces and lighting system through the literature review. Following this, the four variables are predicted to affect lighting appraisal in the original model. Following the paths in the original model starting with the lighting appraisal, environmental satisfaction (as the variable of workplace satisfaction in the original model) is predicted to affect adaptive behaviour for lighting as returning to the beginning of the proposed model.

Starting with the proposal of a SEM model to investigate adaptive behaviour for lighting, the methodology of this research will continue with an experimental study in a full-scale test office in the lighting laboratory. The experiment will contain between-groups and within-subjects designs as in the study of Boyce et al. (2006) and Veitch et al. (2013). The between-groups variables are the internal wall surface colour and lighting system. The within-subjects variables are the occupation position and orientation. Following the experimental study, the collected data will be statistically analysed in order to form the final SEM model.

Through the SEM model, the adaptive behaviour variables will be analysed through a model that evaluates lighting appraisal, room appearance, pleasure and workplace satisfaction. Later, SEM methodology will be implemented into a POE framework as a proposal for the field of lighting.

3. Results

The final SEM model and the proposed POE framework for the field of lighting will be the results of this research following the experimental study. The experimental study will be carried out in Spring 2018.

4. Conclusions

Post-occupancy evaluation (POE) methodology is based on assessing the satisfaction of occupants regarding the built environment they occupy and the performance of the building in relation to user comfort. The background reflections through the literature review have guided this research to a holistic extent, as lighting design should provide glare-free work environments together with achieving the lighting quality and user satisfaction. Adaptive behaviour helps occupants to enhance visual comfort and satisfaction from the lighting conditions. However, published research mostly focused on the overall indoor environmental quality and the impact of the adaptive behaviour on thermal comfort. That is why, this research aims to propose a POE framework in order to assess luminous environment discretely considering adaptive behaviour for visual comfort within a holistic frame. The holistic frame evaluates the parameters related to user, space, task and light.

As part of the POE framework, the feedback and future acts will be proposed. Thus, it is aimed to recommend amendments and future actions based on the identified relations and negative assessments of users in order to improve the luminous environment.

WARM OR COLD FEELINGS: ESTIMATING BIASES IN FIELD STUDIES

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Abstract

1. Motivation, specific objective

Lighting systems with LEDs that allows for control of illumination, in terms of the correlated colour temperature (CCT) and illuminance intensity, is currently being introduced widely in buildings resulting in decreased energy use for lighting systems. There is a great focus on reducing the overall energy use for buildings and the major energy-consuming factor in buildings is related to the regulation of thermal sensation. An earlier laboratory study with fewer biases showed that a shift in thermal sensation could occur when changing the lighting by altering the CCT. Using intelligent lighting control could therefore potentially benefit the overall energy use for buildings if being integrated in the thermal strategy. The overall objectives were to test if it is possible to detect an effect similar to the findings from the laboratory study on the thermal sensation when altering the CCT in real offices environments. The objective of this abstract is to discuss the experimental setup imposed in our field study where supplemental lighting is influenced by daylight and other strong biases. Differences that relate to biases should be estimated and accounted for, but the amount of controls are on the expenses of possible tests of the treatments in focus.

2. Methods

In a real office setting, we test the influence of three different CCT´s of 2800, 3100 and 4000 K on the workers thermal sensation and preferences. Three similar hallways and adjacent single or double offices at the Danish Technical University, Denmark (55°41'38.5"N 12°6'5.7"E) were used. These sections were equipped with LED lighting with central control of CCT and light levels. During the field study the light was on at all times starting from 7 am and onwards unless the workers purposely turned off the light. The electric lighting system was adjusted to 650lx at table height in all CCT settings and it was not possible to regulate the light intensity. The offices had windows to the outside, facing East or West. The experiment was conducted primo January 2018 and lasted for seven weeks. The period was carefully selected leaving minimal influence of the daylight as a central bias and to strengthen the influence of the electric light treatment.

The settings of CCT (treatments) was changed each Sunday in a rotation between the 3 sections having 1 week in between being used as an anchor with CCT of 3100 K in all sections. In this abstract we focus on the anchor weeks and the deviation that relates to the different sections and people answering our questionnaires.

A total of 48 workers were encouraged to participate in the study. The thermal sensation and visual preference were assessed by an online questionnaire with ten (10) specific questions sent out once a week. The workers were asked to rate their individual sensation of the lighting and thermal comfort while situated in their office.

Indoor climate measured as the temperature, RH and CO_2 concentration in the offices during the experiment were logged every 5 minutes along with measurements of outdoor diffuse and direct radiation, temperature and humidity in order to exclude them as possible bias.

3. Results and discussion

This field study differed from (most) laboratory studies in its duration and number of biases. In real office settings, we investigate longer term effects of differences in supplemental lighting CCT on the workers. The workers and sections differed in various ways. Thus, the anchor weeks with CCT of 3100 K in all sections was imposed, to estimate the differences between sections, biases of dealing with different groups of people (sections) along with the influences of continuous changes in the outdoor radiation.

The questionnaire lead to a relatively consistent response rate – resulting in between 28-31 answers the first three weeks and between 20-24 answers the last four weeks (out of 48 requests). The response rate on our questionnaire was in average around 50%, which partly reflect its' length. A short questionnaire, opposed to a more extensive questionnaire, did not allow us to ask question, of e.g. work related distractions, tiredness, stress or sound levels, to further include and account for such biases in later findings, but we do not find that a lower response rate would have been advantageous.

The differences being present between the sections were by anchor weeks measured once for each rotation and at the end. However, imposing the anchor weeks compromised the amount of answers in relations to the treatments of 2800 and 4000 K and extended the test period. Our weekly sent questionnaires (7 weeks) were answered by 19, 135 and 26 workers (180 in total), in relation to treatment settings of 2800, 3100 and 4000 K, respectively. If the study was conducted without the four anchor weeks the test period alone would have been 3 weeks. Execution within 3 weeks would have resulted in a higher response-rate and a more balanced number of answers in relation to the imposed treatments. However, this would compromise the measure of differences that relates to biases influencing the treatment effects. The need of controls for biases will depend on the treatment strength.

4. Conclusions

Field experiments are characterized by having many biases and often a weaker response rate on questionnaire surveys. Our online questionnaire of 10 questions sent out once per week in a field study resulted in an average response rate around 50%. The response rate declined slightly after 3 weeks and varied between 42% and 65%. We are unsure of the need for imposed anchor weeks, since the need for controls of biases influencing the overall result will depend on the treatment strength and survey response rates. However, we stress that differences that relate to biases should be estimated and accounted for.

SUBJECTIVE EVALUATION OF THE ELDERLY PATIENTS AND STAFFS ON THE SPECTRUM TUNABLE LIGHTING APPLIED TO MEDICAL WARDS

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Abstract

1. Motivation, specific objective

Recently, HCL(human centric lighting) is attracting much attention and spreading to various areas. Particularly, as the elderly population grows rapidly and their quality of life becomes a social issue, we have interested in their well-being and developed a spectrum tunable lighting as an implementation of HCL for the elderly medical ward application. Before focusing on the effects of the spectrum tunable lighting on their hormone regulation and their sleep quality, we have summarised their subjective evaluation of satisfaction and improvement before and after the installation of the lighting.

2. Methods

The spectrum tunable lighting module for this study is consisted of 12 different LED chips with narrow band wavelengths and one LED chip with phosphors. The lighting simulates spectrum power distribution of the daylight well and the similarity between them was over 80%. Six lightings were installed to the elderly patient wards, 3 to the male patient ward and 3 to the female one, respectively. A tablet-sized computer with touch screen was used for the lighting control. We applied five different lighting modes changing CCT (K) and illuminance (lux) from 05:00 AM to 21:00 PM. In total, 21 elderly patients participated (12 males, 9 females, 77.6 years old in average). They were randomly assigned to 4 groups, 2 for the male and female experimental groups under the spectrum tunable lighting and 2 for the male and female control groups under the fluorescent lighting. Each group consisted of 6 male patients and 4~5 female ones in different rooms. In addition, 75 medical staffs participated in the evaluation (3 males, 72 females, 38.9 years old in average), 37 for the control group lighting and 38 for the experimental group lighting. They were partially overlapped. To collect subjective evaluation data, we made questionnaires for the elderly patients and medical staffs. Data collection was done first at the control group during developing the spectrum tunable lighting and then at the experimental group later.

3. Results

The questionnaire for the patients included categories about lighting general and use, satisfaction on the ward lighting, and necessity of lighting improvement. The questionnaire for the staffs consisted of the same categories but each category contained more detail questions like lighting control and functions. The results of patients showed that the overall satisfaction was 14% higher but the necessity of improvement was 20% lower at the spectrum tunable lighting compared with the fluorescent lighting. Likewise, the result of staffs showed that the overall satisfaction including lighting control and function was 19.1% higher but the necessity of improvement was 12.7% lower at the spectrum tunable lighting. Particularly, when the scores on the inconvenience that the patients experience under both lightings were compared between the first day and the last day of the 6 days session, it was reduced about 4 times more at the spectrum tunable lighting.

4. Conclusions

Although some improvements for the lighting control is necessary, the results of this study was quite positive. Probably, the existing fluorescent lighting do not have enough brightness and there is no change in brightness and CCT along with the daytime, so the patients and staffs have been experiencing some feelings of unpleasant and inconvenient. If more ICT based controls and functions are used for the spectrum tunable lighting, it will provide a better lighting environment for the elderly patients and hospital staffs, and will contribute to the improvement of their quality of life and work performance.

HUMAN RESPONSIVE ASSESSMENTS FOR DISCOMFORT GLARE USING COMBINED EYE-TRACKING AND PHOTOTMETRIC MEASUREMENTS: A LITERATURE SURVEY

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Abstract

1. Motivation, specific objective

Adjusting indoor environment conditions to human needs is an undeniable ingredient of building’s performance. A basic human need is visually comfortable indoor environment, which is free from glare. Although discomfort from glare is mainly considered as a psychological response based on our subjective evaluation of surrounding environment, investigations on human body responses to indoor conditions can enhance our understanding of physical as well as psychological needs for visual comfort. Both in past and in recent years there have been attempts to extend our understanding of visual comfort and glare in search for objective responses adopting new technologies with focus on body responses, e.g. facial muscles around the eye using electromyography (EMG), pupil oscillation, gaze responses and degree of eye opening using eye-trackers, etc. New advances in eye-tracking methods, however, has led to a more excessive usage of this technology in indoor environment studies. An overview of the adopted eye-tracking methods, data type and the data collection with this technology as well as analysis methods where advantages and limitations of each can be discussed is a prerequisite to the steps forward.

2. Methods

In this study a literature review will be made on human responsive assessment using eye-tracking technology combined with photometric measurements for visual comfort evaluations in experimental phases.

3. Results

As result, a comparable scheme of the existing methods and studies in form of a table will be made. The ultimate goal is to assess the comparability of the obtained data from each adopted method and study. Finally, a discussion will be made on how studies on human responsive assessment for discomfort glare evaluations can be made compatible under a common, comparable and standard scheme.

4. Conclusions

Several studies on visual discomfort glare have been made for better understanding of our physical and objective responses to visual conditions and how they evolve negative subjective responses. A brief overview of existing adopted methodologies in form of a literature survey is presented. The ultimate goal is to create a platform to be able to compare these methods and assess their compatibilities.

EXPLORATION OF DISCOMFORT GLARE IN HUMAN OBSERVERS

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Abstract

1. Objective

As a way to supplement the knowledge base for glare metrics, Pacific Northwest National Laboratory is investigating the following questions for glare source(s), both for interior and exterior lighting:

- How does the position in the visual field affect the response, especially positions near or beyond the edge of the visual field ("overhead glare")
- How does the SPD of the light source affect the glare response?
- How does the size and luminance distribution of the source affect the response (e.g., an array or cluster of smaller LEDs with higher individual luminance compared to larger area, lower luminance sources)?
- How does the background luminance/adaptation luminance affect the glare response, especially when the values are near 1 cd/m^2, simulating a nighttime sky?

2. Methods

Apparatus and Variables

A 1m hemisphere apparatus will be used, with the subject's eyes located at the center of the hemisphere using a chinrest, and dimmable, color-tunable 50 mm diameter LED modules located at 9 horizontal angles and 6 vertical angles from the subject's axis of view. The 5-emitter LED color-tunable modules will be mounted through holes in the hemisphere at elevation angles of -20°, 0°, 20°, 40°, 60°, and 80°above the center axis, and azimuth angles of 0°, 22.5°, 45°, 67.5°, 90°, -22.5°, -45°, -67.5°, and -90° from the center. (See Figures 1 and 2)

Here are the independent variables for the experiments, although it is likely these would have to be tested in different groups or sessions:

- Source location angles relative to the axis of view (30 levels)
  - -20°, 0°, 20°, 40°, 60°, and 80° elevation angles
  - 0°, 22.5°, 45°, 67.5°, and 90° azimuth angles

- Source spectrum (2 levels)
  - ~2400 K on the blackbody locus (actual definition by SPD)
  - ~4000 K on the blackbody locus (actual definition by SPD)

- Background luminance (3 Levels) [also called adaptation luminance]
  - 1 cd/m^2 (simulating outdoor lighting conditions)
  - 10 cd/m^2 (one of the Luckiesh & Guth testing conditions)
  - 100 cd/m^2 (simulating a typical office interior wall luminance)

Dependent Variables:

- Borderline-between-Comfort-and-Discomfort (BCD) luminance, selected by subject through iterative manual dimming of the test source (subjective), or by staircase steps presented by experimenter to zero in on BCD luminance.
- Alternatively, if the approach it to have the subject fixate on a luminous target in the center of the sphere, and match the "brightness" of the off-axis test module to it, the

dependent variable would be the luminance of that selected matching luminance. This would additionally require the subject to respond that the fixation point was either glaring or not glaring.

3. Questions for Tutorial/Workshop

Designing a protocol for testing subjects brings up many questions. In one respect, the testing should duplicate normal eye and head movement, and yet that would confound the results and compromise their applicability in glare metrics. Here are some considerations:

- To get a value for tolerable glare at each of the module angles, we propose mimicking the Luckiesh and Guth experiments from 1949, where the subject is presented a module luminance at a given position in the visual field and asked to raise or lower the luminance until a Borderline-between-comfort-and-discomfort (BCD) value is reached, given the source size, location, size, SPD, and background luminance. Should the BCD setting be determined by the subject using a rotary dimming knob, until the setting looks “right?” Should there be a starting luminance that is either very bright (lowering down from there), or very dim (raising up from there)? What should the starting values be and how are they derived? Should the trials be grouped by starting value, or randomized? How consistent a BCD luminance can a subject produce when dimming from high and low values? Should the resulting two BCD luminances be averaged for a final value? Is it more precise for the experimenter to present luminances in a staircase fashion, eliciting a response of “higher” or “lower” from the subject, arriving at a BCD value using fixed steps?
- Should the gaze of the subject be limited to the center of the sphere, or should the gaze be allowed to wander within the sphere, as one’s gaze normally glances around spaces?
- How consistent are subjects from hour to hour in their responses, or day to day? Is there a way to analyze a subject’s internal consistency? Is there a way to have a companion question or test (non-lighting) that can test for irritability or a bad night’s sleep?
- Is it best to limit a subject’s participation to a single day, or will fatigue warrant spacing the testing out over two or more days?
- Alternatively, should the subject be presented a luminance at the fixation point, and asked to match the “brightness” of that target luminance with the luminance presented off-axis? This would no longer be a BCD task, but a matching task, unless it were accompanied by the subject’s verbal response of “glaring” or “not glaring.” This could yield very useful brightness and glare response data, but would likely increase the number of trials and the length of time each subject spent in the apparatus. (It also requires the subject to fixate on a glaring point of light for some period of time, which can be uncomfortable, fatiguing, and could create afterimages that slow down the testing.)

Human subjects testing for glare is complicated. Insight from other researchers on these questions would be of benefit; and advice on how to avoid experimental quagmires, much appreciated.

THE INFLUENCE OF ARTIFICIAL LIGHTING ON ELEMENTARY PUPIL BEHAVIOUR

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Abstract

1. Motivation, specific objective

One of the key elements in achieving a good indoor climate for learning environments is providing the right quantity and quality of light. When employed correctly, light allows us to see, read, and write comfortably – and it allows us to perform vision-based tasks adequately within indoor spaces. Light has also been found to impact our emotional and physical wellbeing, behaviour, and indoor experience. Through these routes, light influences our ability to perform academically.

Traditionally, there has been significant emphasis on studying the effects of natural light on humans. Various researchers have established that natural light needs to be present in educational environments to achieve optimal conditions for learning. It is therefore also considered an important design parameter by most architects that are tasked with designing educational buildings and that are co-responsible for the orientation of a school building, the façade design and indoor spatial layouts. But as the availability of natural light differs per geographical location and time of day or season, electrical lighting is often required to complement when natural light lacks or is insufficient. This is to ensure students are able to comfortably see, read and write during all hours of use regardless of time of day or weather circumstances. A growing body of evidence also indicates that electrical lighting, similar to natural light, affects students' indoor experience, their wellbeing and behaviour. Not only the quantity, but also the quality of electrical lighting should therefore be considered an important design parameter.

The qualitative effect of electrical light on humans in learning environments can be studied in various ways. This study investigates how spatial atmosphere choreographed by the way that electrical lighting is placed and distributed in an educational space influences pupil behaviour. If an effect is established, our subsequent aim is to understand how electrical lighting design, from an atmospheric point of view, could best support certain learning activities and their behavioural needs.

The specific hypothesis we are testing is that local, focused electrical lighting stimulates quietness amongst elementary pupils whilst executing focus-based learning activities, such as mathematics, reading, writing; individually or in small groups. Based on this knowledge, electrical lighting could be used more specifically to create atmospheres within the same space, which each may support certain curricular activities or room usages.

2. Methods

The main method of investigation is field experimentation in a "live" learning environment: Frederiksbjerg Skole in Aarhus. One of the behavioural parameters measured is pupil noise by measuring the acoustic levels in classrooms. These noise measurements are carefully designed so that the similar focus-based activities are planned with two different lighting distributions, one being an ambient artificial light distribution and the other being a focused artificial light distribution. In each class room, the noise level from similar activities is compared in the two lighting conditions.

Other research methods applied are of qualitative nature: classroom observation, small focus groups with pupils and interviews with teachers–all exposed to these two different light scenarios.

3. Results

Four classrooms are investigated, covering elementary school year 1 to 6 (age 6 to 11). Here we measured noise levels, which after analysis lead to 20 comparable pairs in terms of the activity and the pupil's number with help of video recording analysis. it was found that the focused artificial light distribution reduces the noise level by more than 1 dB in 14 out of 20 comparisons, with the largest

reduction to be 6.3 dB. In the remaining six cases, the difference in noise level was insignificant as the level difference found was less than 1 dB.

Analysis of data collected by our qualitative methods is currently being analysed with no definitive results yet established. Preliminary analysis seems to indicate greater environmental satisfaction by both pupils and teachers for the specific activities studied.

4. Conclusions

The noise level during focus-based activities was measured in a Danish primary school with different lighting conditions. Comparing 20 fair conditions in terms of activity type and number of students, we found that the noise level in 70% of the measured cases were lowered beyond the perceptual limen. This seems to support the hypothesis that atmospheres of local and focused electrical lighting improves the conditions for learning through quietness amongst pupils.