Technology and Health Care 20 (2012) 11–23
DOI 10.3233/THC-2011-0650
IOS Press

Light therapy: Methodological issues from an engineering perspective

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Received 12 July 2011
Revised 23 July 2011

Abstract. Light therapy is increasingly administered and studied as a non-pharmacologic treatment for a variety of health-related problems, including treatment of people with dementia. Light therapy comes in a variety of ways, ranging from being exposed to daylight, to being exposed to light emitted by light boxes and ambient bright light. Light therapy is an area in medicine where medical sciences meet the realms of physics, engineering and technology. Therefore, it is paramount that attention is paid in the methodology of studies to the technical aspects in their full breadth. This paper provides an extensive introduction for non-technical researchers on how to describe and adjust their methodology when involved in lighting therapy research. A specific focus in this manuscript is on ambient bright light, as it is an emerging field within the domain of light therapy. The paper deals with how to (i) describe the lighting equipment, (ii) describe the light measurements, (iii) describe the building and interaction with daylight. Moreover, attention is paid to the uncertainty in standards and guidelines regarding light and lighting for older adults.

Keywords: Methodology, colour temperature, lighting, ambient bright light, illuminance, dementia

1. Introduction

Light therapy is increasingly administered and studied as a non-pharmacologic treatment for a variety of health-related problems, including skin problems (UV-light treatment), obesity, seasonal affective disorder, depression, as well as sleep disturbances and behavioural problems. Light therapy comes in a variety of ways, ranging from being exposed to daylight to being exposed to light from table-mounted devices (light boxes) and ambient bright light. Bright light treatment with the use of light boxes is applied to entrain the biological clock, to modify behavioural symptoms, and improve cognitive functions, by exposing participants, often older persons with dementia, to high levels of light (for

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instance, Lovell et al. [1], Graf et al. [2], Thorpe et al. [3], and Dowling et al. [4]). The latter approach of ambient bright light is rapidly gaining popularity, also for ethical and practical reasons. This treatment encompasses an increase of the general illuminance in rooms by ceiling-mounted lighting in order for non-image forming effects of light to take place. Studies by Rheaume et al. [5], van Someren et al. [6], Riemersma-van der Lek et al. [7], van Hoof et al. [8,9], Sloane et al. [10,11] and Barrick et al. [12], which exposed institutionalised people with dementia to ambient bright light through ceiling-mounted luminaires, showed short-term and long-term effects such as lessened nocturnal unrest, a more stable sleep-wake cycle, possible improvement to restless and agitated behaviour as well as sleep, increased amplitude of the circadian body temperature cycle, and a lessening of cognitive decline. To date, it is unknown how long effects of bright light last and how to predict which persons respond positively to light treatment. Moreover, the minimum and optimum intensities, timing and durations of light therapy are unknown [13]. Light therapy is an area in medicine where medical sciences meet the realms of physics, engineering and technology.

As light and lighting typically belong to the domain of engineers and lighting designers, many important aspects connected to studying and applying light and lighting systems are often overlooked in non-engineering studies. This is illustrated by a Cochrane systematic review by Forbes et al. [13], which assesses the evidence of effectiveness of light therapy in managing cognitive, sleep, functional, behavioural, or psychiatric disturbances associated with dementia. The review includes only randomised clinical trials in which light therapy, at any intensity and duration, was compared with a control group for an effect in people with dementia of all types and degrees of severity. According to Forbes et al. [13], "*. . . there is insufficient evidence to assess the value of light therapy for people with dementia. Most of the available studies are not of high methodological quality and further research is required.*" We would like to add that there are other methodological short-comings in the included studies, which are not related to randomisation. In our view, these serious short-comings are related to engineering, technology, and the physical aspects of lighting. In many studies, these areas are not sufficiently dealt with.

Moreover, the results of the medical studies of light therapy may be used by engineers and product developers, including lighting producers (often globally operation electronics enterprises), as well as installers of lighting equipment, to improve their products and designs [14,15]. In practice, however, this is often made difficult or even impossible by the lack of technological description in the methodology sections of the papers. It is not only the industry that may benefit. Other researchers who engage in (partial) replication or follow-up studies should be made aware of the importance of describing their methodology fully and correctly.

Therefore, the goal of this paper is to present an overview of methodological key points (challenges and solutions), concerning light therapy with an emphasis on ambient bright light, from an engineering perspective, which can be used by researchers studying light therapy, professionals involved in making lighting guidelines, and reviewers of related manuscripts.

In the following sections, we will deal with (i) the description of lighting equipment, (ii) the description of light measurements, (iii) the description of the building and interaction with daylight, and (iv) the uncertainty in standards and guidelines regarding light and lighting for older adults. This is followed by a short conclusion section.

2. Description of lighting equipment

Obviously, describing a lighting application as a "*table-mounted device of 10,000 lux*" is not sufficient. First of all, one should try to provide as many details on the lighting and the device itself: the brand

and type and serial number, the type of light source inside, as well as characteristics of the luminaire or fixture. These characteristics influence the angle at (narrow beam, broad beam), or direction in (up- or down-lighter, wall-washer), which light is emitted. When using existing light boxes, such equipment should comply with the Medical Device Directive MDD93/42/EEC, which was published in 1993 by the European Commission.

There are many features that should be described in a study. For instance, van Hoof et al. [8] described their equipment as follows:

> "*[. . .] five new luminaires of the type Philips Strato TPH710 SKY. Each new fitting contained eight high-intensity fluorescent tubes* (*TL5-49W/827/865*). *The general colour rendering index* (Ra) *of the lighting was 85.*"

The abovementioned information contains information on the type of luminaire (including the angle at which light is emitted, the amount and type of light sources (fluorescent lighting), as well as a correlated colour temperature of 2,700 and 6,500 kelvin respectively. Moreover, the colour rendering index, also known as CRI [15], is provided to the reader. The CRI is a quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source.Including the correct type of lighting used in a study makes it possible to find all characteristics of the lamp, even if not mentioned in the paper, if demanded by the reader.

Lieverse et al. [16] describe home-based bright light treatment for major depressive disorder in older persons. In this study, bright pale blue or dim red light treatment therapy was administered using light boxes that contained a single-layer filter that was wrapped around the fluorescent tubes. The study shows the importance of adequately describing any used filter.

The age, the temperature of the environment, and the dirtiness of the environment of a light source may influence its output. When the age of the lighting is known, it should be mentioned. Moreover, ambient temperature may impact the output of a light source. For instance, the correlated colour temperature of the MASTER TL5 HO ActiViva Active 54W 1SL (17,000 K) was determined at a temperature of 25°C, which may correspond to a temperature of a room in a nursing home. When the ambient temperature gets lower or higher, this soon causes a deviation of 0.005 in CIE XY coordinates of the CIE 1931 [17, 18] colour space chromaticity diagram. The CIE system allows the specification of colour matches for a standard observer using colour matching functions. These colour-matching functions for normal human observers are the fundamental basis of colorimetry. In case of 17,000 K lighting, this can mean a shift of 2,000 K in realised colour temperature [9]. This is another reason to always monitor the ambient temperature during experiments. In studies by Viola et al. [19] and Meesters et al. [20], which used 17,000 K lighting in offices and for people suffering from a major depression with a seasonal pattern, neither ambient temperature nor colour temperature of the emitted light were measured and reported.

In lighting studies, the distance to the light source and the size of the emitting surface should be provided, as with normal, diverting light sources, the luminous flux decays with distance from a light source.

Friedman et al. [21] described their methodology as follows:

> "*In all conditions, desk lights of the same size* (*48.26 × 45.72 × 27.94 cm*), *style* (*extendable arm with an adjustable lamp head positioned individually to maximize light exposure without shining light into participants' eyes*) *and manufacturer [. . .] were used. Every light held two fluorescent lamps each 36 W and 3000 K, behind a UV-filtering plastic screen* (*43.5 × 13.2 cm*). *[. . .] In both bright groups, light fixtures were calibrated to produce 10,000 lux full spectrum white light at the point of emission. The research assistant placed the light fixture at eye level, with 45.72 cm between the fixture face and middle of the participant's forehead, on a table or desk covered with white, reflective, photographic paper.*"

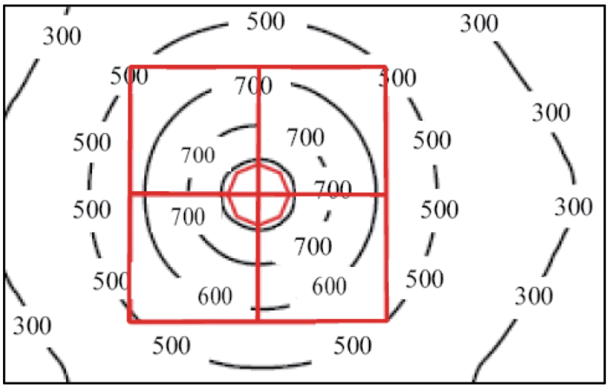

Fig. 1. Clustered luminaire lay-out (represented by 2 by 2 squares) simulated in DIALux, showing isographs for horizontal illuminances at a height of 1.2 metres. Software can help determine the amount of light participants are exposed to. Example taken and adapted from van Hoof et al. [9], used with permission.

Apart from describing the size of the fixture, and illuminance, the distance to the light source has been stated, too. Dimensions are very specific with two decimals. The exact illuminance at the eye level was not provided in the description. Sadly, the exact type of fluorescent tube has not been stated, which would have given clues to the exact spectral distribution of the light. The correlated colour temperature of the light provides only a first approximation, and is a single value unit, just as the CRI. In practice, the environment also influences the spectral composition of the light, as well as the available daylight.

Ouslander et al. [22] described their lighting scheme as follows: "*Late-day* (*generally between the hours of 5:00 and 8:00 p.m.*) *exposure for up to 2 hours to bright, full-spectrum light* (*Sunray II1, SunBox Company, Gaithersburg, MD*) *that generated approximately 1,467 lux at an average distance of approximately 4 feet from the light source.*" The illuminance of 1,467 is very specific and is likely to be subject to change, as there may be an additional contribution of daylight.

When the light emitted is not constant over time, for instance, in dynamic or cycled lighting protocols, the lighting schedule needs to be given in the paper together with a time frame. An example can be found in Spreeuwenberg et al. [23]: "*[L]ighting schedules began with a low-intensity, warm light* (*400 lux, 3,300 K*) *in the morning, starting at 7:00 a.m. Within 2 hours, the light became more intense and cooler, with a maximum* (*1,300 lux, 4,900 K*) *at 9:00 a.m. [. . .] [T]he intensity and color of the lights decreased gradually 1 hour before lunchtime* (*12:00 noon*) *and increased gradually again within 1 hour after lunchtime* (*1:00 p.m.*). *In the first lighting schedule, the cool, intense light lasted until 5:00 p.m. and decreased within 1.5 hours to provide a relaxing atmosphere in the evening. In the second lighting schedule, the cool, intense light lasted until 7:00 p.m.*"

The exact differences of using dynamic versus static lighting are still unknown and should be subject of further study. When participants are exposed to a combination of daylight and electrical light (note: there is no such thing as artificial light), the light output should be given as 'added electrical light', as it is added to a certain level of daylight.

The positioning of the luminaires in the space is another point of interest. Brawley [24] mentions that bright fixtures in the ceiling are not a substitute for indirectly lit ceilings, especially in large open areas. That is why luminaires need to be positioned with care. Simulations can be a wonderful tool in determining the amount of daylight and best layout of lighting applications [25]. Computer software as DIALux can be used to the arrangement of luminaires, so that the largest illuminance levels on the vertical eye level can eventually be obtained in practice (Fig. 1). With the use of the validated light simulation tool Radiance, the daylight conditions (illuminances) in a room can be simulated, and later validated with light measurements in practice. If software is used, the software version should be mentioned since (new) features, settings, and bug fixes are constantly added and changed, which may influence the results.

When designing clustered lighting, one should be aware that when using lamps with integrated electrical ballasts or control gears (in (compact) fluorescent lights) or drivers (in LEDs), the output of the lighting cannot be easily deducted from the normal lumen per watt ratio, as the ballasts or drivers can negatively influence the efficiency of such light sources.

Apart from a good description of the lighting applications, the most important thing is to measure the lighting conditions right. Some lighting applications do not deliver the output that has actually been written on the package or in the manual. Moreover, there is always an interaction with the environment and, possibly, with daylight.

3. Description of light measurements

There are two major types of light therapy studies; studies carried out in laboratory settings and studies conducted in the field. The latter type is relevant for clinical practice, for instance, when exposing people with dementia to ambient bright light in a non-invasive manner. A disadvantage of field studies is that light exposure is more difficult to describe and control. Moreover, when conducting research using ceiling-mounted luminaires, researchers should always consider the much debated Hawthorne effect [26]. In the 1930s, managers of the Hawthorne Plant of the Western Electric Company tried to see whether raising the level of lighting would increase their workers' productivity. They found that it did but that the changes were only temporary, and similar results were found when lighting levels were actually lowered. The people on the work floor knew they were being monitored, which probably made them work harder. It is unknown to which degree participants with dementia are aware of on-going research and how any awareness actually influences the results of field studies and therapeutic outcomes.

Since the direction of light at the retina plays an import role in non-visual effects of lighting, the way light is generally measured should be reconsidered. In clinical studies, it is true exposure at the eye which matters; not hypothetical exposures or presumed exposures. This is what is often measured and reported in practice.

The most important measurement is that of illuminance, expressed in lux-units. In some American papers foot-candles are still used as a measure, which is an imperial measure that is not in line with the scientific use of SI-units (for instance, La Garce [27] and Hegde and Rhodes [28]). Current standards and guidelines [for instance [29–31]] are based on horizontal illuminances (E_h), i.e., the illuminance measured on a horizontal plane, for instance, a table top which is acceptable for most visual aspects of lighting research [32,33]. Vertical illuminances, in turn, are measured in a perpendicular fashion to the horizontal plane, i.e., under a 90 degree angle. The method and instrument for measuring both horizontal and vertical illuminances are, thus, similar, albeit under a different angle. In only a few publications on lighting for older persons, vertical illuminances are provided [33,34]. The difference between horizontal and vertical illuminances and their measurement are shown in Fig. 2. For research on the non-visual aspects, measuring horizontal illuminances is of little use for describing the actual exposure to light, as the human eye is not positioned on top of the head. One should measure the light levels in one‘s gazing direction, taking into account the participant‘s viewing direction and angle, in order to get an accurate impression of the true exposure. The vertical illuminance is a good measure if one gazes straight forward, without a tilt in one's neck. For the non-visual aspects, it might be that illuminance is not the correct value, as illuminance is directly related to the cones. Moreover, in theory, there exists a unit of

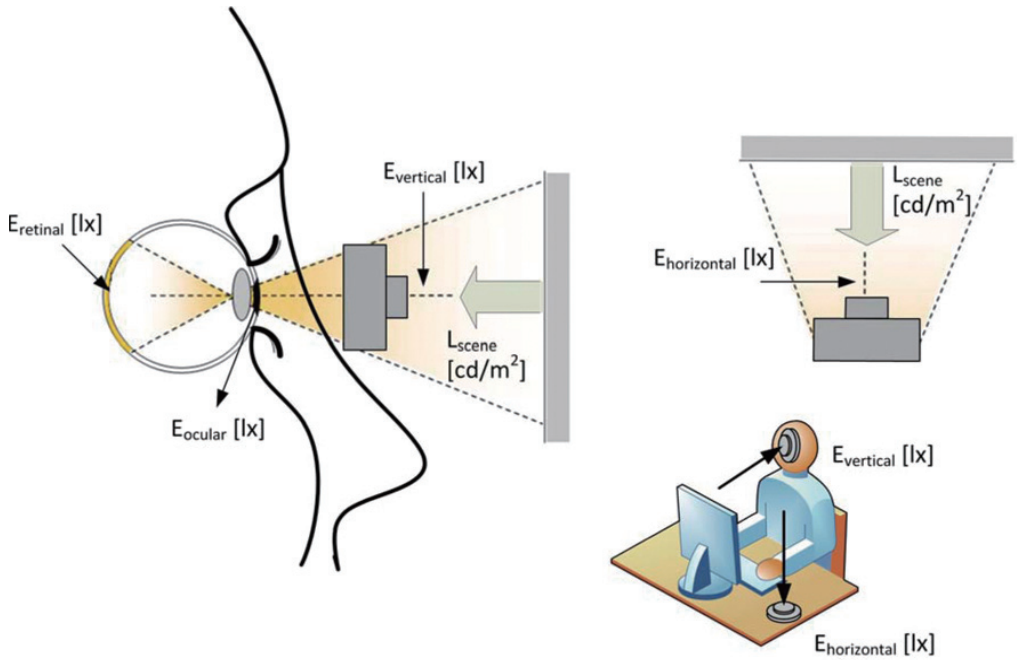

Fig. 2. The differences between horizontal and vertical illuminances, and between ocular and retinal illuminances when measuring vertical illuminances. Taken and adapted from Ariës [32] and Sinoo et al. [33], used with permission.

conventional retinal illuminance, the troland unit [Td] [35,36]. This unit corrects light measurements by scaling outcomes by the effective pupil size. In practice, most studies provide horizontal illuminances, although sometimes this is not made clear in the text. In a study on treating patients with Seasonal Affective Disorder (SAD) in a light therapy room, Rastad et al. [37] provide illuminances in terms of "*horizontally as the eyes see*". This leads to uncertainty about what is actually meant, and whether Rastad and colleagues provide horizontal or vertical illuminances.

As mentioned before, when assessing light for visual aspects, vertical illuminances (E_v) at the eye level (also known as corneal or ocular illuminance) should thus be measured in combination with horizontal illuminances in order to allow comparison with standards (Fig. 2). The measurement thereof should preferably be conducted continuously or with regular intervals. This gives a good representation of actual exposures in lux and the duration thereof. When measuring light exposure, one could place a sensor at the eye level pointing into the gazing direction (for instance, Bierman et al. [38], Hubalek et al. [39] and Cuttle [40]). Moreover, special spectacles, brooches, visors and goggles can be put together in a laboratory, which include sensors for measuring light parameters and which contain a data logger. At the same time, these goggles may pose limitations in use for certain user groups, including older people with dementia, who do not recognise the devices and remove them. A more sophisticated instrument is presented in Figueiro et al. [41], who used a daysimeter to measure over-time personal circadian and photopic light exposures in a study with adolescent participants. Such a daysimeter employs two photosensors separately calibrated to provide a photopic and a short-wavelength response to optical radiation. The two sensors are juxtaposed at the end of a printed circuit board in order to create a compact, in-line package that rests on the side of a participant's head and places the sensors close to the same plane as the participant's cornea. The daysimeter is also equipped with accelerometers and a solid-state thermometer.

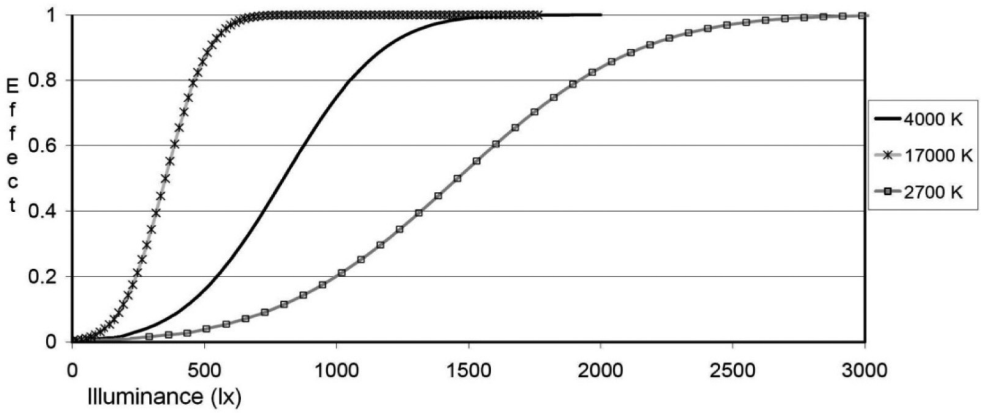

Fig. 3. Hypothesised size of non-visual effects of light during daytime for different illuminance levels at the eye and different colour temperatures. Taken and adapted from Górnicka [46], used with permission.

A table-mounted device for measuring illuminances may provide a solution, but may get lost in group settings, when there are people with dementia showing hoarding behaviour. Wrist-worn devices appear in the literature (for instance, Friedman et al. [21]), but such instruments do not measure ocular illuminances, and are therefore only suitable for a very rough indication, for example, how long people were exposed to very high light conditions. Tamura and Iwata [42] reported the following correlation ($r = 0.82$, $n = 28{,}055$) Eq. (1) between the illumination level at the eye and the wrist, for which differences can be compensated for:

$$\lg E_{eye} = 0.6854 \cdot \lg E_{wrist} + 0.658 \tag{1}$$

This equation allows for the interpretation of wrist-results to ocular levels. Moreover, wrist-worn devices may get covered by sleeves.

However, practical and ethical considerations played a role, for instance, the availability of readily available wrist-worn actigraphs versus less practical measuring goggles or neck-worn pendants.

Sadly, there is no all-encompassing equation to calculate E_v from E_h for indoor purposes. In practice, these two illuminances are not equal and cannot be derived from one another in indoor settings where the illuminances depend on daylight access and the output of lighting systems and dimensions of luminaires. Moreover, not all types of fluorescents lights have the same luminous flux at a given power. This should be considered when comparing two different lighting solutions to each other.

Another method of expressing exposure is by providing the readers with a photon density count, as is done by Sletten et al. [43]. In their controlled laboratory study, they exposed pupil-dilated participants to monochromatic short wavelength blue (λmax 456 nm) and medium-wavelength green λmax 548 nm) light matched for a photon density of $6{\cdot}10^{13}$ photons/cm^2/s. Such detailed and precise description is only possible for laboratory studies, not for studies conducted in the field.

When measuring light, it is important to account for the spectrum of the ambient light. This does not have to be similar to the output of a lighting fixture, as daylight, furniture and interior design all have an impact on the light indoors. Measuring the colour temperature of the light in kelvins provides a first indication of the colour of the light and the spectrum. This is of importance when looking at the blue-contents of the light spectrum and the non-image forming effects (Fig. 3).

Exposure to light ($\lambda \sim$ 460–480 nm) is the most important stimulus for synchronising the circadian system, which is orchestrated by the hypothalamic suprachiasmatic nuclei (SCN). In older adults, the orchestration by the SCN requires ocular light levels that are significantly higher than those required for proper vision. An additional problem is formed by the ageing of the eye and exposure to UV-light that leads to opacification and yellowing of the vitreous and the lens, limiting the amount of bluish light reaching the retinal ganglion cells [44]. In addition, findings by Gooley et al. [45] suggest that cone photoreceptors contribute to non-visual responses at the beginning of a light exposure and at low irradiances. Melanopsin, which is present in the intrinsically photosensitive retinal ganglion cells in the human eye, appears to be the primary circadian photopigment in response to long-duration light exposure and at high irradiances. Light therapy might, thus, be optimised by stimulating both photoreceptor systems.

Górnicka [46] calculated the non-image forming (NIF) effects of lamps for office situations. She found that the higher the colour temperature of light, the more NIF output the light yields. For instance, a lighting condition of 17,000 K would give 3.4 times more NIF output than the condition of 2,700 K (Fig. 3). Due to the opacification and yellowing of the vitreous and the lens in ageing persons, and thus increased filtering of the short wavelength light emitted by the 17,000 K light source, this ratio might be different in practice and needs further investigation. The colour temperature provides a first indication of the spectral distribution or composition of the light, but is of course not the same. It can be measured using a colorimeter. Please note that the colour temperature given by manufacturers and the actual colour temperature of the light on the eye deviate in practice, and should therefore be measured in studies. One could also measure the spectrum of the electrical light using a spectrometer, but one should keep in mind that this is not what enters the eye when not directly exposed to the light source and when there is ambient light. So in studies, spectral distribution should also be measured at the eye level. In addition, many lighting producers provide graphs of the spectral distribution of their products, for instance, shown for every 5 nm frequency band in μW/lm.

Based on the previous sections, we show a random example of an insufficiently described research methodology and explain what we do not know. Barrick et al. [12] described the technical part of their lighting intervention as follows. "*A computerized system maintained lighting intensity at 2000–3000 lux during [bright light treatment] hours, and at 500–600 lux* (*industry minimum standard lighting for task areas*) *during the remainder of daylight hours and the entire Standard lighting period. The treatment areas were restricted to the common areas of each unit.*" Based on their study, their key point is that "*[b]right light therapy is not associated with improvement in behavioral symptoms among persons with dementia.*" Based on the description of their lighting system, such a conclusion is not sufficiently supported by the reported evidence. First of all, we do not know what type of lighting system has been tested. Second, we do not know to what extent people were exposed to the lighting, and what the luminous output of the lighting really was. Moreover, are illuminances measured horizontally or vertically? We also have no further information on the way the computerised system worked. Perhaps the authors did not find any results because the relevant wavelengths of light were not present in the light their participants were exposed to.

Exposure duration in the field or compliance to light therapy is hardly ever measured due to practical objections. One of the positive exceptions is a study by Most et al. [47]. In their study, light therapy compliance was measured by a motion detector connected to the light box. A registration logger was connected to this motion detector. Moreover, participants were asked at every assessment whether long period of absence or other compliance issues had occurred. Apart from the study by Most et al. [47], particular attention should be paid to one‘s activity pattern and the corresponding exposure to ambient light (also daylight). Participants, who go out for a daily walk, may be exposed to higher light levels while being outside. Results are then incorrectly attributed to the light therapy, due to a lack of registration. This brings us to aspects of daylight in the built environment.

4. Description of the building and interaction with daylight

Particularly when conducting field studies, it is important to provide more data on the environment and the building itself. Supplying data on just the lighting equipment is not enough. The space in which an experiment is conducted needs to be described in more detail, too. The furniture and interior design of a room influence the spectrum of the ambient light and interact with the colour temperature. Reflection coefficients of materials determine the luminances in a room. Humans do not 'experience' illuminances, but luminances.

Moreover, it is important to mention the distance the participants are seated away from any windows or other daylight openings as skylights. Daylight rapidly decays with distance from a window, but in case one measures vertical illuminances for people facing a window, this decay is less pronounced. In general, the interaction with daylight is small(er), when farther away from windows. Moreover, a person's orientation is of importance: when facing away from the window, daylight exposure is smaller than when facing towards a window or being seated parallel to the window's surface. There is also a relevant effect of daylight on colour temperature of the ambient light, which results in cooler (= higher) colour temperatures in practice compared to, for instance, a 2,700 K light source. The best option is to provide a floor plan, showing daylight openings, furniture, and the position of the participants (and their main viewing direction) and the position of the lighting equipment. The need for such a floor plan and description of the room depends on the study; if one measures the actual light on the eye, the rest may become less relevant.

Apart from the orientation of the room and its windows, the distance to the windows (and eye contact or not) needs to be described, too. This included a description of the surface area of the windows in square metres, as well as the ratio between the window surface and floor surface, the height of a room, and the type of glass used including its transmission coefficient. Windows of thermally insulating glass filter out large portions of daylight. An impression of the contribution of daylight can be obtained via sensors placed against the window pane with a suction cup. Obstructions in façade/window zone, such as trees, overhangs, buildings, the glass itself, and luminance/sun control systems ('curtains', 'blinds') should ideally be described too. Ouslander et al. [22] already mentioned that future research should consider different protocols for bright light exposure and the use of outdoor light where feasible.

Apart from light, researchers should consider the physical indoor environment as a whole. The physical indoor environment comprises the thermal environment, the indoor air quality, lighting, and the acoustic environment. In a broader sense, it constitutes all that the individual hears, sees, feels, tastes, and smells, and all together, these parameters have an impact on whether someone feels comfortable. A description of the operative temperature and even sound pressure level (preferably a continuous data set), clothing ensembles and type of activity people are involved in are of importance, as they can influence behaviour, comfort and perception and acceptance of the visual environment.

La Garce [27] studied the effects of specific lighting interventions, designed to control natural afternoon daylight effects in an interior environment, on the disruptive behaviours of people with dementia. For a year, participants alternated between the control and intervention rooms, and behaviours were videotaped for approximately 992 hours. Double blind observation of participants was made to record the frequency of disruptive behaviours, and the percentage of change from the control to the experimental environmental was calculated.

> La Garce [27]: "*The environmental lighting interventions placed in the experimental environment included full spectrum fluorescent lighting, micro-slatted glazed windows, and electronic controls to maintain a constant level of light intensity at approximately 110 ft. candles. The light level in the*

control environment was also approximately 110 ft. candles, diminished only slightly throughout the course of a day and was evenly distributed throughout the space because of the large, high window facing south and the sloped ceiling. The electric lighting in both the control and experimental environments consisted of tandem-wired, tubular fluorescent fixtures. The environmental interventions were designed to control the effects of natural daylight changes across the afternoon. These changes included: (*1*) *white light at noon changing to yellow/red in later afternoon,* (*2*) *shadow patterns of light moving with changing angles of the afternoon sun, and* (*3*) *light levels diminishing in later afternoon. The spectral distribution of the fluorescent lamps used in the experimental environment was as close a technological match to natural daylight at noon* (*5500K and 96 CRI*) *as was currently possible.*"

The incorporation of daylight and the way observations were conducted, makes this study unique in its kind.

5. Uncertainty in standards and guidelines

To date, there are no extensive documents on lighting for older people, which can serve as an underlying basis when conducting research, for instance, for the determination of threshold levels, timing and the exposure duration. There is, however, a growing interest within the building community for the non-visual aspects of light [48]. This may, in turn, lead to improvements of current guidelines and the development of new protocols. For example, nursing homes do not only have a residential function, i.e., providing home to older adults who require a high level of care. Nursing homes are also workspaces for nursing staff and other professionals. The European standard EN 12464-1 [29] summarises recommendations of lighting of indoor work places. The standard specifies illuminances for health care facilities, such as waiting rooms, corridors, examination rooms, and spaces for diagnostics in hospitals. Nursing homes are not included in this standard. The standard does not specifically include colour temperature for health care facilities. This standard specifies lighting conditions in terms of horizontal illuminances, not their vertical counterparts.

The (professional) literature contains recommendations that have obvious short-comings. A threshold for illuminance often found in literature is "*a bright condition of 1,000 lx*". It is hypothesised that high-intensity lighting, with illuminances of well over 1,000 lx, may sort effects targeted by light therapy. There is, however, little scientific basis for this threshold, see, for instance, Phipps-Nelson et al. [49]. Noell-Waggoner [50] provided an overview of lighting requirements for older adults with dementia. Light should be directed toward the visual task and not toward the eyes of the viewer. In order to avoid glare from daylight caused by the high contrast ratio between daylight and dim interior electric lighting, light should be balanced, for instance, through bringing daylight into the space from more than one direct source. Moreover, levels of the ambient electric light can be increased throughout the room in order to achieve better balance. In order for NIF-effects to occur, older adults need light levels in the range of 2,500 to 3,000 lx, which are levels that are ten times higher than needed for good vision.

Apart from the international standards, there are national initiatives as the guideline by the Dutch Society for Illumination (*Nederlandse Stichting Voor Verlichtingskunde, NSVV*) [30] that deal with light for older adults. This particular guideline by NSVV does not distinguish between horizontal and vertical illuminances either, nor does this guideline provide very high illuminances (over 3,000 lx) for biological stimulation. The Dementia Services Development Centre of the University of Stirling has published a guideline of light and lighting design for people with dementia, which provides additional data on the use of lights and recommends various lighting levels [31]. There need to be more efforts to improve current standards and guidelines to account for light therapy and ambient bright light.

6. Conclusions

Light therapy is an interdisciplinary field of study and practice, where medical sciences meet technology and engineering. This paper shows that many of the articles describing light therapy studies are not sufficiently considering the various light parameters and lighting systems in the methodology sections. This, in turn, negatively impacts the reliability of the reported results. For future laboratory and field studies, researchers may find guidance in this article to provide a more uniform methodology. By improving the methodology, researchers can make their results more useable for the lighting industry, which in the long run, has to come up with practical lighting solutions for use in nursing homes and psychiatric health care. At the same time, a light therapy study protocol should be developed and existing standards should be revised in order to support research and practice. As the domain of light therapy research is interdisciplinary in character, collaborations between engineers, psychologist and medical scientists should be encouraged in order to share their expertise and improve the quality of their scientific work.

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