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Performance of personally worn dosimeters to study non-image forming effects of light: Assessment methods

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ABSTRACT

When determining the effects of light on human beings, it is essential to correctly measure the effects, and to correctly measure the adequate properties of light. Therefore, it is important to know what is being measured and know the quality of the measurement devices. This paper describes simple methods for identifying three quality indices; the directional response index, the linearity index and the temperature index. These indices are also checked for several commonly used portable light measurement devices. The results stresses what was already assumed, the quality and the outcome of these devices under different circumstances were very different. Also, the location were these devices are normally worn has an impact on the results. The deviation range between worn vertically at eye level and the wrist is between 11% (outdoor) to 27% (indoor). The smallest deviation, both in indoor and outdoor, was found when the device was placed on the sides of the eye (7%).

1. Introduction

Since the discovery of a novel retinal non-image forming (NIF) photoreceptor [1,2], it has been established that eye-mediated light has not only a visual function but also an image-forming function. Light also influences the mental state (ie. [3–5]) alertness (i.e. [6,7], and behaviour/quality of life (i.e. [8–10], via stimulation of the photoreceptors; rods and cones, and the non-image forming receptors (intrinsically photosensitive retinal ganglion cells (ipRGCs)) [11]. Light entering the eyes and activating photo sensitive cells follows the pathway to the Suprachiasmatic Nucleus (SCN). The SCN is the primary oscillator of the Circadian Time Structure (CTS) and is responsible for individual hormone regulation [12]. Light entering the eye during the night can suppress the production of the hormone melatonin [13,14], as an example of how light exposure can influence the sleep-wake rhythm. However, the ipRGCs are not equally sensitive to all wavelengths. The ipRGCs comprise only a small fraction of the total ganglion cell population and the differences between the photopic and the circadian spectral sensitivities may cause inaccuracies in the measures of light exposure. Khademagha et al. [15] provided a graph which shows the different action spectra between the visual (photopic) spectral sensitivity and the considered action spectrum for melatonin suppression based on the results of different papers. Although not one best fit for an action spectrum could be defined, clear is that the curve is shifted towards the shorter wavelength (see Fig. 1).

Personally worn photosensitive dosimeters are generally used to establish the relationship between light and a photo biological effect. Since the characteristics of the eye-mediated light exposure largely determine the effect, the quality of measurement devices, is of high importance to achieve an accurate quantification of the light exposure in relation to the targeted effect of a study. A methodological approach needs to be defined for dosimetry device measuring the effective exposure with respect to the non-image forming effects of optical radiation.

Different photosensitive dosimeters have become commercially available, but what exactly is being measured, including accuracy is not always clear. The main variances between the personally worn dosimeters are:

1 The position the device is worn on the body. Relevant photosensitive cells are located in the retina indicating that the eye

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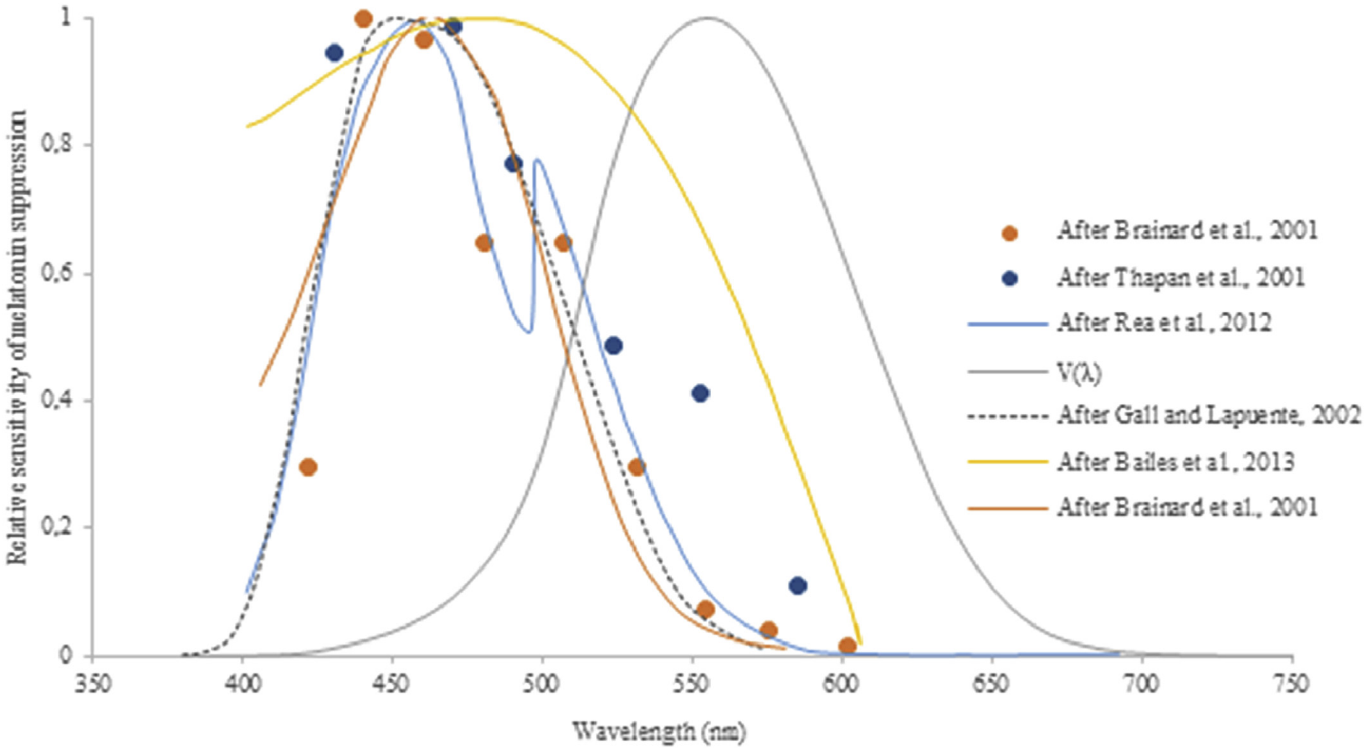

Fig. 1. Sensitivity curves V(λ) and the different C(λ) by Khademagha et al. [15].

position would be preferred. Many dosimeters are worn as wrist device, combining actigraphy and light exposure. These devices are worn on the non-dominant wrist, recommended for gaining the most reliable actigraphy data but less accurate when referring to the light exposure entering the eye. In a study on the influence of annoyance to different personally worn light measurement devices, it was concluded that, prior to an effect study, individual annoyance and obtrusiveness of the devices might impact the results and should be assessed as well [16].

2 The type of light sensitive cells. Originally, light was solely studied for vision-related effects. That is why the great majority of studies on NIF-effects between 1980 and 2000 used photopic light quantified stimuli. Current insights point out that photo biological effects of light are influenced by the spectral distribution, irradiance level, geometric conditions of exposure and their intermediate changes, as well as by the time and duration of exposure [17]. Hence, photometric quantities, like illuminance (E) or correlated colour temperature (CCT) are related to vision, and therefore not appropriate for describing non-image forming effects [11]. Therefore the latest dosimeters tend to be equipped with sensors matching other spectral responsivity curves like the erythropic, chloropic, rhodopic, melanopic, and cyanopic [18].

3 Data logging. Since the dose of the exposure is relevant, the device should be able to log data. Most devices are equipped with such feature where by changing the log frequency the measurement period can be altered from hours to several days.

4 Cost. The costs for perusing a personally worn dosimeter can be from less than € 20 to more than €2000. The different components necessary to make such wearable device are not that expensive allowing for 'self-made' devices. The more expensive devices are equipped with different light sensors and dedicated software is developed to analyse the data.

The impact of light on human life is established but the radiation characteristics which induces a particular effect remain less conclusive, as stated in the Technical Note 003:2015 by the CIE [18] "Measurements of timing and the biological factors of primary interest to circadian neuroendocrine and neurobehavioural-related photobiology researchers are typically accurate and chosen to describe the quantities of direct interest. By contrast, light stimuli have often been less well described by researchers." A clarification for this is that firstly, the descriptions of methodologies contained many differences which make a comparison between results almost impossible [19]. The specific lighting condition needs to be described in great detail to establish the connection between light(ing) characteristics and the non-image-forming effects [20]. Secondly, the type of portable devices used to measure the light exposure were not identical and measured different quantities to express the exposure.

Moreover, the recent technical note from the international commission on illumination (CIE) [21] states the challenge of defining and using correct terminology and quantities for different health-related effects. In their communication, among others, the CIE identifies the need for extra research for instrumentation calibration and development of field measurement methods.

Acknowledging the importance of using the correct quantities does not mean that other measurement inaccuracies are to be neglected. Since many devices are worn on the wrist it is questionable how well these values measured correlate to the eye position. Therefore, light measurements were carried out for different positions on the body to find the most accurate position and to establish the deviation.

Next to indicating the most accurate measurement position on the body, the performance of different dosimeters, as currently used in effect studies, is determined. This is determined according to the standard [22] and is expressed in classes [23]. Unawareness of these inaccuracies might result in relating certain effects to an