FIELD STUDIES OF HUMAN LIGHT EXPOSURE DURING EVERYDAY ACTIVITIES – METHODOLOGICAL ASPECTS AND INITIAL RESULTS

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ABSTRACT

Daylight significantly affects our health and our general well-being. At the same time, a daylight deficiency can be observed in modern society. We spend much of our time in buildings and vehicles, a trend which is reinforced by current re-urbanisation processes. Light exposure studies based on photometric sensors allow connections to be made between light exposure, human spatial environments and lifestyles. Although earlier light exposure studies based on interviews and personal log books are known [1], surveys that are supported by reliable measured data have only become possible recently due to modern technological advances. The rapid development of so-called "wearables" makes it feasible to use various sensors to obtain information on user behaviour and external influences (illuminance, temperature, etc.) on the user. Preliminary experimental tests with students at the University of Wuppertal have provided an initial basis to assess sensor-supported light exposure studies. The potential and deficits of various loggers and their position on the wearer's body were investigated and field tests were carried out by students equipped with simple data loggers. The primary objective was to optimise the methodology as a result of the experience gained, with the goal of developing a procedure to quantify the light exposure of different groups of test persons during their everyday activities.

Classification schemes in the form of individual light signatures and frequency distributions of the illuminance values measured during the test periods provide initial qualitative information on the test persons' exposure to light. However, the investigations to date also identify obstacles to analysing the measured results. For example, the predetermined measurement parameters, the spectral sensitivity of the photometer or the position of the logger on the wearer's body all influence the measured results and the conclusions which can be drawn from them.

Keywords: light exposure, measurement technology, field studies

INTRODUCTION

The effects of daylight on human health and well-being are of concern to physicians, chronobiologists, psychologists, architects and light designers. Recent studies have demonstrated the positive effect of daylight on the circadian rhythm, the synthesis of vitamin D3 and general vitality and well-being, for example [2]. Natural short-wave radiation has different effects on the human body, depending on its spectral range. "Visible light" (380 – 780 nm) affects melatonin suppression via the eyes, whereas UV-B radiation (290 – 315 nm) influences the formation of vitamin D3 through the skin [3]. Thus, sunlight is the most important source for vitamin D3 synthesis in the body, but at the same time, excessive exposure to sunlight is the main cause of skin cancer (UV-B) [4]. Behaviour related to daylight exposure is thus becoming increasingly relevant to preventive health and medical research. Among other effects, it has been determined that daylight as a resource is becoming scarcer in modern society. On average, people in modern societies spend about 80 – 90 % of their time in buildings and vehicles [1, 5] and follow a daily routine which is increasingly disparate from the natural day-night rhythm [6]. Artificial lighting, increasingly densely populated urban spaces and changes in work-related and leisure behaviour have effects on individual exposure to daylight. Urbanisation and its effects on society and life in towns and cities have been observed since the industrialisation of the 19th century [7]. As a reaction to cramped urban living conditions, social residential reforms such as the "Garden City" models of the 20th century demanded a spatial balance between the various functions within a city, as well as between town and country [8]. The aim was to achieve socially equable and healthy urban living by town planning that led to a well-balanced distribution of building density. Today, the trend toward re-urbanisation [9] and the resulting rezoning toward higher-density building mean that the quality of urban life can be expected to change anew. The effect of densification processes and an urban lifestyle on light exposure is of interest, as are the possible consequences for health and well-being.

Quantitative exposure studies allow conclusions to be drawn on human interaction with daylight in urban and suburban habitats. Preliminary studies by students have investigated the measurement technology potential of selected simple, wearable data logger systems. The studies focused on critically assessing how field tests applying mobile data loggers could be used to gain reliable information on daylight exposure of groups of test persons over longer periods of time.

METHODOLOGY

As a first step, the requirements on the data loggers were defined. Selected loggers from different price categories were compared by identifying positive features and drawbacks. Over a period of two days, one test person checked possible effects on measurement results and user comfort due to the sensor position on the wearer's body. Student field tests, divided into two test periods (summer, autumn) of three weeks each, as well as further investigations with children, provided initial, measurement-based estimates of the light exposure of the test persons. In addition to determining the feasibility of such field tests, the primary focus was on developing the evaluation methodology and interpreting the initial measured results.

Comparison of Photometric Loggers

The rapid expansion of wearable technology has led to increased development of mobile data loggers with different integrated sensors. Thus, various parameters of the human working and living environment can be measured to investigate biological rhythms, sleep-wake cycles, activity levels and well-being, among other aspects.

To quantify light exposure, photometric sensors are used which measure the illuminance (lux), and in some cases, also the spectral irradiance ($mW\ m^{-2}\ nm^{-1}$) and/or the UV irradiance. Measurement of the UV radiation allows not only analysis relating to vitamin D3 synthesis but also differentiation between indoor and outdoor spaces, as conventional window glass is opaque to UV radiation. In order to draw conclusions on the availability of light in different outdoor spaces, the location of the test persons has to be determined. In this case, the logger also needs an additional Bluetooth connection to allow synchronised GPS tracking via a mobile phone or smart watch.

In a preliminary investigation, three selected loggers were assessed with regard to qualitative differences. This included comparisons of their technical construction and handling, as well as data capacity and data processing. The sensor position and attachment options of the loggers were assessed with respect to possible wearing positions. Comparative measurements with the various data loggers and a reference luxmeter, outdoors and indoors (immediately behind a window), provided information on the measurement accuracy and range. The loggers were placed next to each other on a horizontal surface and the measurement intervals of one minute were synchronised. A number of measurement series were carried out under different daylight conditions, allowing conclusions to be drawn on the measurement accuracy of the sensors at different illuminance levels.

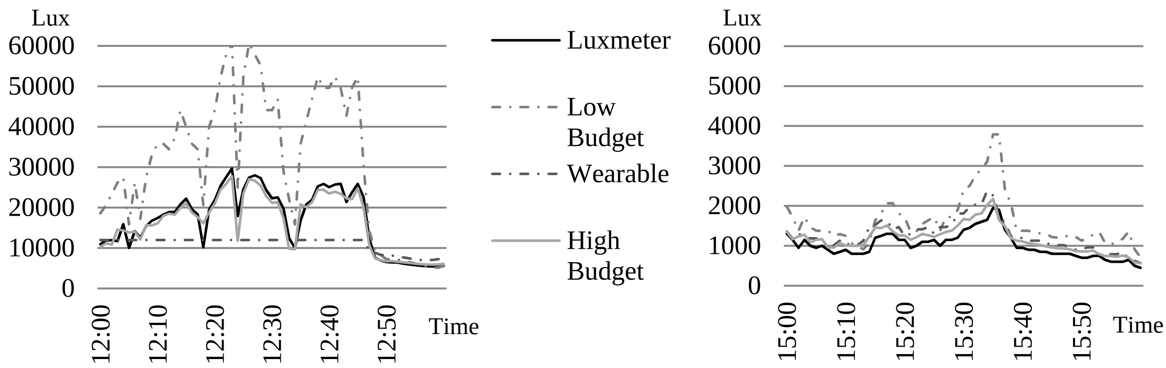


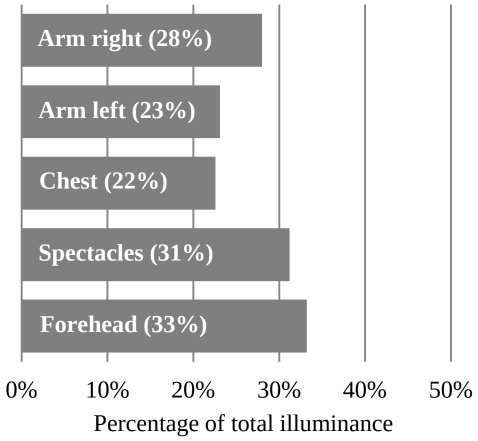
Figure 1: (left) Comparison of the measured outdoor illuminance (1-minute intervals) determined by three selected photometers and a professional luxmeter.

Figure 2: (right) Comparison of the measured illuminance for daylight indoors behind an uncoated double glazing.

Figures 1 and 2 present examples of illuminance time series measured outdoors and indoors. The measurements indicate the problems caused by the wide range of illuminance values with regard to measurement resolution and accuracy. An appropriate sensor and suitable AD converter must be selected, as otherwise either the dynamic range is too small or the resolution is too coarse. For instance, the “wearable” logger features better measurement accuracy in the low illuminance range, but it reaches saturation already at 12 000 lux. As a result, outdoor measurements cannot differentiate between cloudy and sunny conditions. The “low-budget” logger has a wider measurement range, at the cost of resolution. The values measured by this logger deviate significantly from those of the luxmeter for higher illuminance values. Only the “high-budget” logger provided comparably good values in both the high and the low illuminance ranges. All loggers measured more accurately in the low illuminance range.

Wearing Position for Logger

To draw conclusions about the effect of daylight exposure on the circadian rhythm, the sensor must be positioned close to the wearer’s eye. To determine the relationship between daylight exposure and vitamin D3 synthesis, measurements near exposed skin are needed. Specifically, this implies measurements on the head and also on the upper body and arms. In addition, one test person was equipped with loggers on his forehead, spectacles, chest, right and left upper arms, to check the effect of the data logger wearing position on handling, user comfort and measurement results. The loggers were worn continuously during daily activities and tested for their practicability. They were taken off and kept in the same room as the test person while that person slept or washed. The predefined measurement period of two days provided information on various requirements specific to the weather and the user. Meteorological data for comparison were recorded with five identical sensors mounted outdoors. The measurement results were subsequently analysed and interpreted, taking previous values for the test person into account.



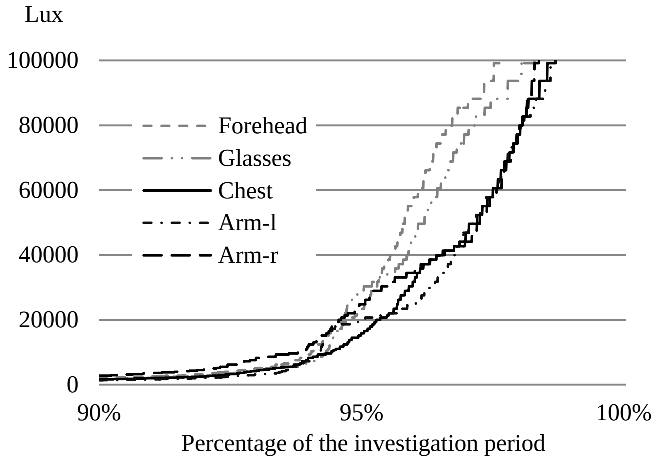


Figure 3: (left) Percentage of total illuminance measured by sensors worn on the body with respect to the reference outdoor values (average of four vertically mounted senses facing the four compass directions) in a period of two days.

Figure 4: (right) Frequency distribution of the illuminance values recorded by loggers worn at different positions.

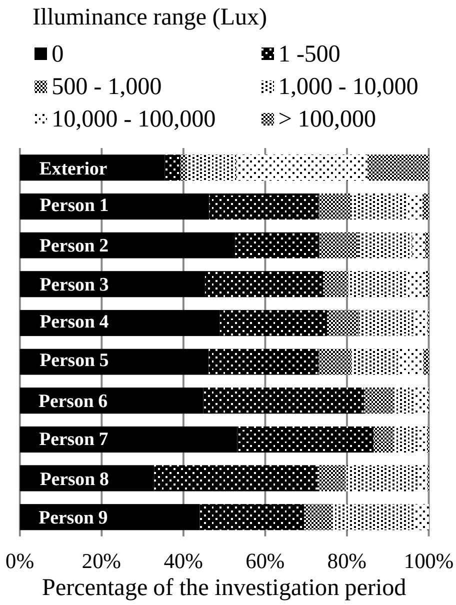
The position and orientation of the sensors affect the measured results. Figure 3 shows the percentage of total illuminance measured by sensors worn on the body with respect to the reference outdoor values. The sensors mounted on the forehead and spectacles measured similar values. However, there are differences between the head zone and the chest, and between the right and left upper arms. The illuminance frequency distribution in Figure 4 illustrates that during this test period, the sensors on the forehead and spectacles measured a larger proportion of higher illuminance values than those attached to the upper arms. The exposed position of the sensors near the head had a direct effect on the measured results.

Field Tests with Students

An essential part of the preliminary investigations drew on measurement-based field tests with students of the University of Wuppertal, Germany. Two test periods in summer and autumn, each lasting three weeks, were intended to provide information on the students' exposure to light, taking the seasonal variation in available daylight into account. The three-week test period each time meant that a broad spectrum of living and working situations for the students was sampled (meteorological conditions, examination phase, holidays…)

The experimental design prescribed that each of the students wore a "low-budget" logger on his/her upper right arm (sensor mounted vertically and facing away from the right side of the body). In the context of these preliminary studies, the focus was on practicability and initial evaluation rather than on spectral response and measurement accuracy of the sensor. The relatively inexpensive, "low-budget" data logger featured a sufficiently wide measurement range and could be attached simply to the upper right arm with a Velcro® strap. During the field studies, illuminance and temperature data were recorded by the logger in 5-minute intervals. Meteorological reference data were supplied by the same type of logger, which was mounted on the university roof with the sensor oriented horizontally. As in the previous measurements comparing different wearing positions, the loggers were removed and kept in the same room as the test person while that person slept or washed. As a source of complementary information, the students kept individual log books of their activities.

The measured data were analysed on the basis of classification schemes in the form of individual light exposure signatures and frequency distributions (Figure 5). These provide information on user behaviour and characteristic features of light exposure, and guarantee good comparability of the various exposure profiles. Figure 6 illustrates how the temporal distribution underlying the exposure profiles can be presented and analysed in detail with the help of a carpet plot. Regular patterns and deviations in the daily schedule of the test persons become evident. By combining this information with that in the activity log books, the effects of the circadian rhythm and living and working habits on light exposure can be investigated. Increasing or decreasing illuminance values (near 0 lux) in the morning and evening hours allow conclusions to be drawn on the sleep-wake rhythm. In addition, it is interesting to note the recognisable effects of weekends on leisure activity and the correspondingly higher light exposure then.



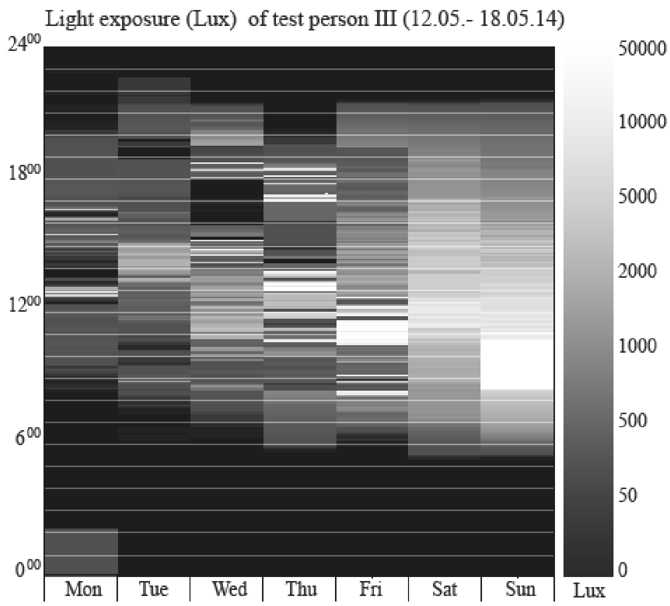


Figure 5: (left) Comparison of the light exposure signatures of nine students based on measured illuminance values, classified according to illuminance ranges.

Figure 6: (right) Carpet plot depicting the temporal distribution of the light exposure measured for one student during the period from 12.05.2014 to 18.05.2014.

CONCLUSIONS

The investigations revealed the potential and deficits of measurement-based light exposure studies. The choice of sensor determines the quality and the potential evaluation context of the measured results. Consequently, before field tests are started, it is important to determine the context in which information on light exposure is needed (melatonin, vitamin D3, skin cancer, well-being). Relatively inexpensive loggers already allow initial analyses to be made of the test persons' exposure to light. Going further, more expensive systems allow the incident light to be analysed spectrally and can provide information on UV-B radiation (differentiation between indoors and outdoors, vitamin D3) or blue-saturated light (melatonin, attentiveness). Further, the sensor position affects the measured results. Conclusions about the interaction between daylight exposure, melatonin and vitamin D3 production become more reliable if measurements are made near the head. However, a logger cannot be attached to the head without an additional mounting structure, which can be uncomfortable for the user. Pressure due to spectacles or head coverings can affect the user's well-being negatively. The loggers vary in their suitability for mounting on spectacles, depending on the position of the sensor in the logger casing design, and the resulting effect on the wearer's field of view.

Attaching a logger to the chest or upper arm with a Velcro® strap or safety pins is comparatively simple, but the measured results are more prone to error. These result from the loggers being covered by or removed together with clothing items (e.g. jackets, sweaters). The field tests with students demonstrated the practicability of using the loggers over longer periods of time. The measurement period is limited by the data capacity of the loggers, taking the selected measurement interval into account. Bluetooth-supported loggers which can save the data in an external cloud, such that they become accessible via Internet, offer an advantage here. The project team can then already react to unanticipated behaviour by the test persons during the test period. Overall, close cooperation between the test persons and the experiment supervisors is necessary to reduce the risk of unusable measurement results. The development of suitable analytical methods allows information on light exposure to be extracted, ranging from identification of typical features up to detailed, time-dependent analysis of exposure profiles with the help of carpet plots, activity log books and location detection by GPS.

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