LED Office Lighting to Promote Performance and Well-Being

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Abstract. This paper aims to introduce a research project to investigate and compare the effect of dynamic lighting on people for different light sources in an office setting. Basic differences of short term effects on human between static and dynamic lighting as well as light-emitting diodes (LED) and fluorescent lamps will be investigated in a laboratory study. Two identical rooms will be set up, with the light source LED and fluorescent lamp being the only difference. Four different dynamic sequences will be compared for each light source. Therefore eight lighting situations will be investigated. Long-term effects will be investigated within a field study of one year. To study the impact of dynamic lighting on performance and well-being different methods will be used as questionnaires, tests and the collection of physical data, especially heart rate variability.

Keywords: lighting, office, dynamic, LED, heart rate variability, well-being.

1 Introduction

Within the last years the lighting community saw two major changes. A new light source, the LED, appeared on the scene. And a till then unknown third photoreceptor, the intrinsically photoreceptive ganglion cell (ipRGC) has been found. The ipRGC has been identified as the link between lighting and many biological functions, especially endocrine and circadian rhythms [1-3].

M.M. Robertson (Ed.): Ergonomics and Health Aspects, HCII 2011, LNCS 6779, pp. 68–77, 2011.

Since then numerous studies have been undertaken to investigate the link between lighting and its impact on human health and well-being. Brainard et al. [4, 5] and Thapan et al. [6] studied the action spectrum of the melatonin suppression at night and could find a maximum at 460nm. Ten years later we know that blue-enriched light as well as high levels of illumination and dynamic lighting enhance alertness and vigilance [7-12]. The activating effects of high color temperature lighting can be improved by planar light sources or indirect lighting using the ceiling or walls [13]. But we also know that one should not increase vigilance and alertness of people ignoring the time of day and the natural rhythm, since this could create several disorders [14-17].

With dynamic lighting during the day it should be possible to enhance well-being. Increased illuminance levels and high color temperature in the early afternoon together with a relaxing atmosphere generated through warm white light and low illuminance levels in the evening will help to stabilize circadian rhythms [18, 19]. This does not only lead to an increased performance during the day but also to an improved sleep quality at night [20].

Besides the paradigmatic change in indoor lighting due to increased knowledge about the biological effects the difference of the spectral light distribution of LED compared to conventional lamps has to be taken into account. The new light source is now not only used in event lighting and media applications anymore. It starts to capture the market of indoor lighting and will soon be used in various applications, e.g. offices, schools and nursing homes.

The above mentioned studies were performed using conventional light sources, such as fluorescent lamps. Due to the different spectral distribution of LED compared to fluorescent lamps (Fig.1) it has to be questioned whether the results of former studies on the impact of light on humans can be replicated using LED lighting.

2 Basic Knowledge

For billions of years, humans have been exposed to light of specific spectral compositions. In particular humans are exposed to sun light, which changes its colour (and temperature) within the day [21]. Sun light supports the production of serotonin and vitamin D which can improve health and subjective well-being [22-25]. Vitamin D is pivotal for the calcium metabolism, for the built-up of bone matter [26]. Serotonin (5-HT) is a carrier substance in the brain at which dearth depressions can occur [27]. 5-HT is necessary for the production of melatonin, which is built in the pineal gland and has a connection to light as well as to the circadian rhythm [28]. Light represses the production of melatonin especially the blue and green fractions (465nm), the short-wave part of the visible spectrum [2, 4, 5, 29-31].

In fact, short-wavelength monochromatic light has a higher impact than light of longer wavelengths on circadian phase-shift, melatonin-suppression, the increase of subjective and objective alertness as well as the change of the body temperature [5]. Numerous studies concerning the color temperature of light have shown that fluorescent lamps with a high color temperature have a bigger impact on the stated effects than fluorescent lamps with lower color temperature [8-11].

Since electric lighting has been introduced people spend more and more time inside while lacking sufficient amounts of daylight. Until a few years ago interior lighting design was restrained only to the visual needs of humans. But we now know that the existing artificial lighting systems cannot be a satisfying replacement for natural daylight. In fact, many people suffer from issues due to light deficiency, such as lack of concentration and motivation, fatigue or even sleeping disorders and depression [32].

By implementing well-designed lighting systems, the interior lighting can help to increase concentration and motivation as well as improve subjective and objective well-being. Circadian rhythms can be stabilised leading to a better sleeping quality. We have to take into account that light at the wrong time could have opposite effects and might therefore cause health problems.

Former Studies. Within the last years numerous studies have been undertaken to investigate the link between the lighting systems and their impact on health and well-being. Most of these studies on the effect of dynamic lighting on performance and well-being have been run using conventional light sources, such as fluorescent lamps. The different effects of varied illumination levels and color temperatures on the well-being, the acceptability of the lighting system and the performance of the subjects have been analyzed in diverse applications (e.g. schools, offices, nursing homes).

High illumination levels as well as high color temperatures increase subject's alertness and activity. Also higher concentration and motivation levels could be found when lighting with high illumination levels and high color temperatures were applied [8, 13, 18]. To add to this effect planar light sources or indirect lighting using the walls and the ceiling will be useful. In contrast low illumination levels and color temperature create a relaxing atmosphere [13].

In office lighting mixed systems are preferred compared to direct or indirect lighting only. Furthermore, a lighting system should not be designed focused on an increase of the worker's performance only. If the circadian rhythm is disturbed by a purely activating lighting scenario, this could lead to several disorders, as studies on shift workers have shown [14].

Current knowledge about the biological effects of indoor lighting is largely based on results from laboratory or short term studies. We do not know much about the impact of light in real life situations. There are a few field studies as well, those looking into the effects of light sequences in the course of several weeks or months while rating well-being and health only at the beginning and the end of the intervention time. We do not have sufficient data on the progression of health related parameters, well-being, sleeping quality and performance over the course of at least one year.

3 Objects of Study

So far, studies on the effects of light on human, especially in office environments, have mainly employed conventional light sources like fluorescent lamps. However, currently there is an increasing demand on office lighting systems with LED, whose characteristics vary significantly from those of fluorescent lamps. The most obvious difference between the two light sources is their shape, the LED being a point light source compared to the linear shape of a fluorescent lamp. But also less obvious differences may result in different effects on well-being, perception and performance of people. Compared to the fluorescent lamp the LED has a continuous spectrum. This affects not only the visual perception, but might also result in different biologic effects of the lighting system.

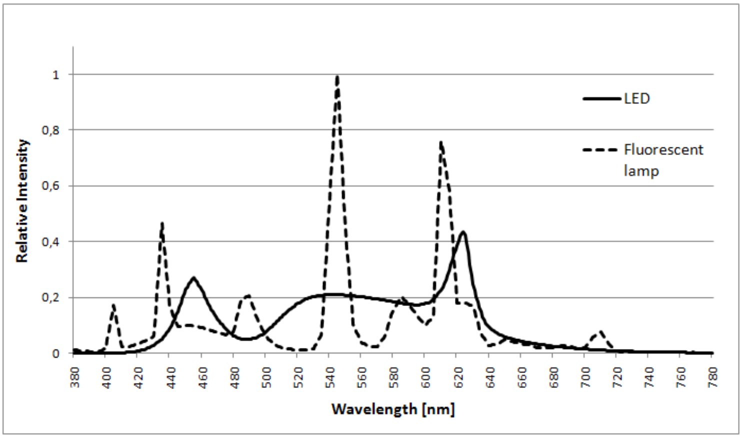

Fig. 1. Spectral distribution of an LED and a fluorescent lamp at 4000K

We will investigate the long-term effects of dynamic office lighting on humans, compared for the light sources LED and fluorescent lamp due to their varying spectra. The dynamic office lighting used in this study will be designed considering the knowledge from chronobiological research and investigations within the community of lighting technology. Fig. 2 shows the dynamic change of color temperatures, illumination levels and the shares of indirect lighting. The office day starts with lower lighting levels, high direct lighting and a low color temperature of 3000K in the morning. Until noon all parameters increase to their maximum of about 1000 to 1500lx and 6500K at 1pm. During the afternoon color temperature, illumination level and share of indirect lighting decrease to reach their starting point by the end of the working day. The dynamic sequence is designed to promote the circadian rhythm, increase sleeping quality and therefore improve well-being and performance of office workers.

4 Methods

The short term effects of dynamic office lighting will be investigated in a laboratory setting. Two identical rooms will be set up, with the light source LED and fluorescent lamp being the only difference. Four different sequences will be compared for each light source: one static lighting situation and one dynamic sequence with three maximum levels of illumination (800lx, 1200lx, 1500lx). Combined with the two light sources eight lighting situations will be investigated.

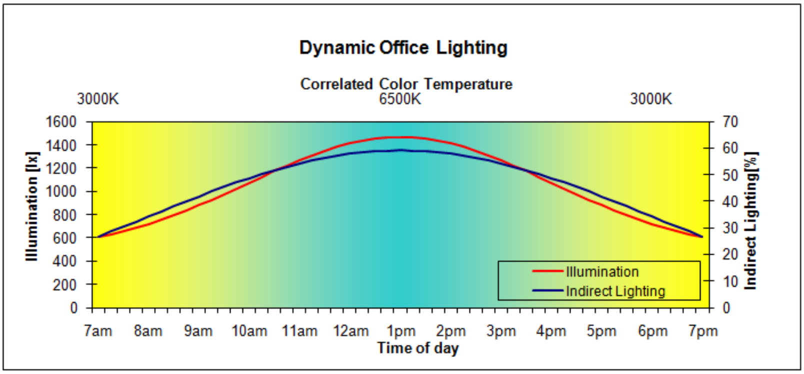

Fig. 2. Dynamic change of color temperature, illuminance and indirect lighting

Forty subjects in the age of 20 to 55, male and female, will be measured in their subjective well-being, concentration and visual performance at several times a day. Additionally physiological data will be collected measuring heart rate variability (HRV) to study activation cycles and recovery periods as well as sleep quality of the subjects. The independent variables are the light source (LED and fluorescent lamp) and the lighting sequence, as described above. Dependent variables are subjective well-being, concentration, sleep quality, visual perception and HRV.

The subjects will spend an entire workday in the laboratory for each sequence, eight workdays altogether. To avoid biased results due to different weekdays, they will be in the laboratory at the same weekday in a time span of eight weeks.

The day starts with an evaluation of the subjective sleeping quality (HRI-Sleep [33]), the general quality of life (QLI [34]), health (SF-12 [35]; MKSL [36]) and stress and recovery behavior (EBF [37]). During the day we will test concentration (KLT-R [38]), sleepiness (Karolinska Sleepiness Scale [39]) and visual perception of colors and contrast, two times in the morning and two times in the afternoon. At each measuring point the subjects will rate their subjective well-being (BSKE [40]). In the evening they will answer the MKSL-questionnaire on physical complaints once again and rate their subjective well-being during the day in general. Each day the subject spends in the laboratory, HRV will be collected continuously over 24 hours for objective cardiac-autonomic data on stress and recovery.

To investigate the long term effects over the course of one year a field study will take place in a company in Austria. Two open plan offices will be equipped with the new lighting system, allowing dynamic office lighting. One office will be provided with LED luminaires, the other office will be lighted by fluorescent lamps. In a third office we will keep the already existing lighting system in order to install a control group. In the course of one year the subjects will rate their well-being, concentration and subjective health every week. During the days of measurement 24h-HRV will be collected as indicator for sleep quality, objective well-being and stress-recreation-patterns [16].

5 HRV – Heart Rate and Heart Rate Variability as Indicators of Human Health

As mentioned, we will use HRV as an indicator for physiological health related effects. Heart rate is one of the main operating parameters of a complex network in which the heart, circulation, respiration, temperature, and metabolism respond to physical and psycho-mental influences. On top of intrinsic chronobiological rhythms, the heart rate gets its typical temporal structure that can be measured as variability [16, 41]. The modulations of instantaneous heart rate are analysed to describe the tone (activity) of both branches of the autonomous nervous system. Rapid changes are assigned to the vagus (primary nerve of the parasympathetic part of the autonomous nervous system). The vagus is active at rest and in states of recreation. The sympathetic nervous system acts more slowly and becomes active when the organism is strongly stimulated.

During the last three decades an increasing interest evolved in the identification of heart rate variability (HRV) and its value as a health indicator [42]. It is based on the assumption that an organisms flexibility and ability to respond to external stimuli is reflected appropriately in the activity of the autonomic nervous system and thus in the heart rate fluctuations. The clinical relevance of HRV was first highlighted by Hon and Lee (1965, quoted by [42]). Basically, HRV decreases when stress occurs as a result of the activity of the sympathetic nervous system [43]. Psychological stressors increase the cardiac activation of the sympathetic nervous system which can be noticed by an increased concentration of plasmacatecholamin and altered autonomic parameters of HRV [44, 45]. The Framingham study [46, 47] found a connection between a decreased HRV and increased mortality.

Lately, HRV was established not only in occupational medicine [48], sports [49, 50] and in sleep medicine [51-56] but also in wide areas of health care and disease prevention. Especially in the case of heart-related pathologies, such as myocardial infarction [57, 58], heart transplants and other cardiovascular diseases [59, 60], the measurement of HRV is recognized as an additional diagnosis and process support [61, 62]. But also in other diseases, such as diabetes [60, 63] or indexed psychiatric problems, such as depression [64], anxiety disorders [41, 65], in sleep research and cancer [17], new approaches of treatments are arising from practical application of HRV analysis.

Basically, any condition modulating autonomic nervous system activity is a candidate for HRV assessment. This very general approach puts HRV in the position of providing a parameter bundle of low specificity but high sensitivity for overall assessment of an organism’s status and reactions to environmental changes. Due to high interindividual variances alongside good reproducibility, repeated measurement designs are the method of choice. Thereby, the age-related differences in heart rate variability between men and women have to be taken into account [66].

Stress and Recreation. Madden and Savard [67] found significant links between HRV and mental stress. Moriguchi et al. [68] documented an increase in the sympathetic nervous activity performing mental tasks depending on the degree of stress. Hjortskov et al. [69] described the HRV as a more sensitive and specific indicator for stress experienced at computer work compared with simultaneously performed blood pressure measurements. The neurobiological bases of the link between psychological stress and HRV are depicted e.g. by Critchley et al. [70].

The literature and research results up to now, clearly illustrate that not enough attention is currently paid to the possible health related effects of lighting situations at the workplace. With our study design and the applied methods we should be able to measure psychophysiological activation and recovery processes over a working day to demonstrate the importance of office-lighting for people's well-being and performance. The multidimensional approach, combining the use of questionnaires, performance tests and circadian heart rate variability measurements, should be able to give reliable and valid conclusions for future configurations of specific lighting situations at the workplace.

6 Outlook

At the time of the presentation at the HCII2011 in Orlando, it is in its second phase. We hope to be able to give an overview on the first results.

Acknowledgements. Sincere thanks are given to the federal states Vorarlberg and Tirol, FFG, AUVA and Blaha for supporting the project.

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