Human Factors in Lighting

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Abstract. This paper addresses current research activities on the interaction between light and humans, including visual perception as well as cognitive, biological, and emotional factors. We focus on issues which can be deployed at office workplaces and describe how we adopt these findings at the "nLightened Workplace" at the Fraunhofer Institute for Industrial Engineering. The nLightenend Workplace integrates illumination and information displays in offices. We present our latest developments such as "Heliosity". We will give an outlook on our future research work on human factors in lighting.

Keywords: Lighting, Office Work, Human Factors, Performance and Health.

1 Introduction

Designs of ergonomic workplaces cover all elements of a working system and the relevant environmental factors. Light is an important factor for the appropriate interaction of humans, technology and information.

More than half of the people asked in a random sample in a study done by Çakir/Çakir [5] describe the lighting situation in their job with negative attributes like unpleasantly and unfriendly. Very often artificial lighting is not only considered as unpleasant, but even as health-impairing. Natural light even affects vital functions of the human organism.

Due to architectural restrictions however, healthy and productivity-enhancing natural light in offices can rarely be ensured. Missing natural light makes artificial lighting indispensable especially in winter after dusk. Sophisticated artificial lighting concepts can prevent health impairments and support motivation and performance capability of humans. To avoid tiredness during winter or noon and to prevent seasonal affective disorder or changes in mood, the employment of smart lighting concepts is essential.

The impact of light to humans can be summarized in three main topics:

- Visualization of Information
- Illumination of the environment and
- Effects on Health

In this paper we will address these topics with innovative concepts to improve the quality of life and save energy at the same time.

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2 Impacts of Light on Humans

2.1 Biological Effects of Light

The biological scope of light differs vastly from the visual effect. Light that infiltrates over the eye and skin into the body is an essential external trigger for the endogenous rhythms. It triggers the endogenous oscillator according to rhythms of days, weeks and years and therefore the function of ductless glands and cell metabolism. Hence light takes regulative effects on the complex arrangement of functions of the organism. The communication of the viscera is based on the release of the hormone melatonin into the cardiovascular system [15].

The amount of melatonin that is produced by the pineal gland is regulated by the circadian photoreceptor melanopsin in the retina of the eye. Melatonin causes tiredness and regulates the sleep-awake-rhythm and further circadian organ functions. The production of melatonin is aborted through effect of light [1].

The sensibility of melanopsin dependant on the wavelength is shown in figure 1. The maximum of the melatonin suppression and therefore the circadian activation is at 464 nanometers, which corresponds to blue light [16].

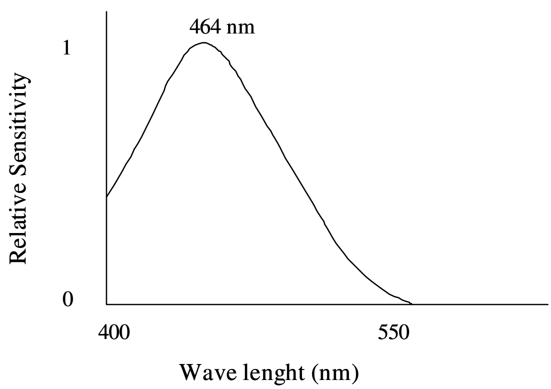

Fig. 1. Circadian sensitivity curve (Brainard et al. 2001)

2.2 Emotional Effects of Light

Balanced illumination and enjoyable colour temperatures attend the well being in the short and long term [10] [13] ascribes a relaxing effect for the raise of well being, appetite and quality of sleep to the natural sunlight. The emotional effect of light is sensed extremely individual and depends on experiences and moods. Thus light and illumination conditions that are comparably comfortable for all people do not exist. However the following effects are indentified:

Cool and white illumination with narrow spectrum lead to increased hyperactivity, exhaustion, excitability and attention deficits, whereas lamps with full spectrum contribute to an overcoming of problems with reading and learning [12].

Glaring illumination can result in an inner tension, psychological fatigue and impairment of condition. Glaring is often associated with the attributes colourless and cold (more than special colour temperatures).

2.3 Effects of Light on the Cognitive Performance

Cognitive functioning domains range from simple attention to logical reasoning, working memory, long-term memory, and complex executive functions that are usually assessed through objective, task-oriented performance measures. The main cognitive processes are shown in figure 2.

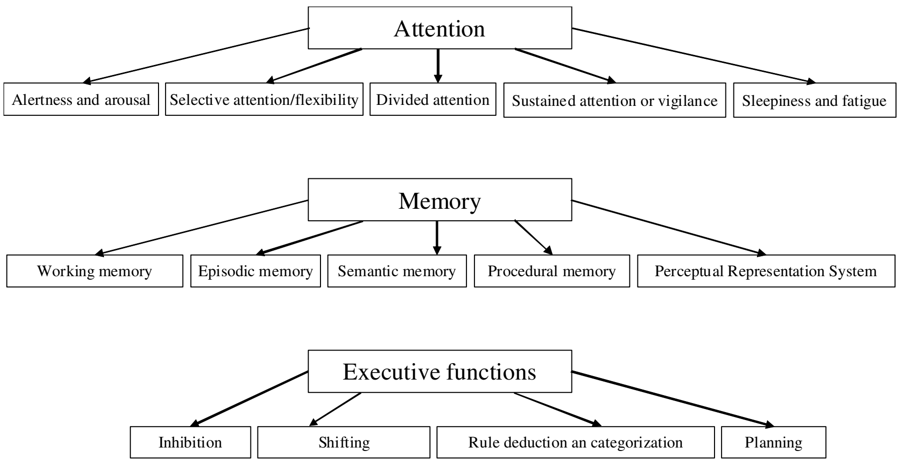

Fig. 2. Overview of the main cognitive processes

Some cognitive functions – like attention and activation – are connected to the temporary devolution of the circadian rhythm. This is revealed through the coincidence of drops in performance and a minimum of body temperature, which serves as an approved indicator for the circadian rhythm [4]. In more simple visual tasks the maxima of body temperature and performance curve occur nearly simultaneous at about 8:00 p.m.

Attention denotes a central cognitive function. It is imaginable in many degrees from casual remark to full attention, whereas the last one can be hold only a short time (Schmidt et al. 2007). *Vigilance* is related to frequency of occurrence, signal strength and other context criteria (e.g. light). [9] proved that an enhancement of illumination strength can raise vigilance. For complex tasks a precipitous ascent of vigilance in the morning, a performance maximum at early afternoon and a subsequent slow decline of performance is denoted (Folkard 1990). This difference to the devolution in simple, visual tasks arises probably from the influence of sleep regulating processes [7]. The sleep requirement increases over the period of being awake (Fig. 3). This seems to derogate the execution of more complex cognitive tasks in a bigger extent than the one of more simple visual tasks.

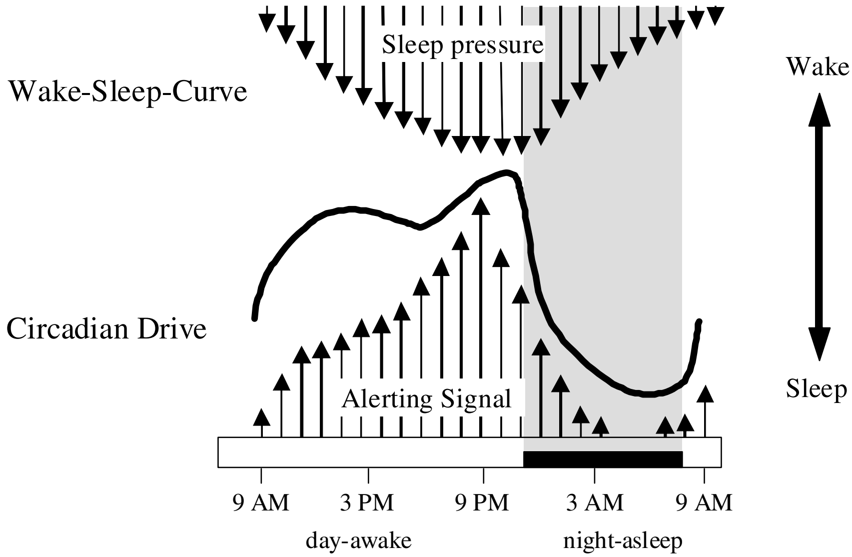

Fig. 3. Circadian und homeostatic processes as mediator of being awake and asleep (Edgar et al. 1993)

Central influence on the attention has *activation* – that is also called alertness [1]. Fluctuations of attention reflect a varying level of activation. The influence of light on the activation is obvious in the natural circadian rhythm. Corresponding to Cajochen (2007) tiredness and performance decline can be countered by short-wave blue light.

3 Impulses for the Arrangement of Light at the Workspace

Effects of light on mood, performance and health remained widely unconsidered in work design. Only since few years the interest in an integrated arrangement of light has increased. Illumination systems that are designed according to the requirements of humans establish appropriate conditions for cognitive and physiological work and contribute to maintaining health of working people. To attune the situation of illumination to human's needs the following criteria should be followed:

- Conservation of photometric quality criteria,
- with reasonable dynamic change of light,
- under inclusion of natural day light.

Emotional effects refer basically to individual subjectivity and can't be appropriately determined by means of objective criteria. For coloured lighting design the principles of harmony should be considered. Beside the principles for creation of harmony of colours mainly the avoidance of disharmonies and the comprehension of a preferably wide spectrum should be regarded.

For the human oriented light design it is recommended that illumination is not perceived as a static, consistent installation in a room and his restricting surfaces.

At present a series of prototypical installations do exist that emit blue light of high intensity with a wavelength of 464 nanometers. By suppression of the release of melatonin an activating impact of the circadian rhythm is aspired. Because the circadian effective receptor is settled in the eye, an influence over the display as primary viewing object for screen handling seems to be effective. One should keep in mind that the circadian sensitivity curve differs from the one of the blue cones. The maximum of the blue receptors is at 420 nanometers, the one of melanopsin is at 464 nanometers. The level of activation should be designed in such a manner that additional burdens or even resistances are avoided. A shift of the circadian rhythm is imaginable if strong exposure to light at the workspace occurs during the morning or in the late evening (Fig. 4). The diagram clarifies how an exhausting phase shift rises with increasing level of illumination.

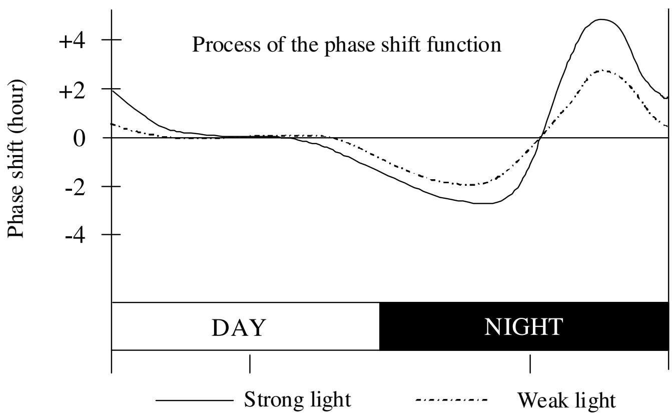

Fig. 4. Influence of the moment of exposure to light on the phase shift of body temperature for two levels of illumination (Rea 2002)

4 The nLightened Workplace at Fraunhofer IAO

Today's display workplaces have one or two screens with approximately 20 inch diagonal. These displays-centered workplaces were shaped more by technical conditions than by human requirements concerning performance and health. Apart from the ergonomic weaknesses of the limited screen surface and thereby same time representable information capacity limited the operational procedure.

The n-Lightened workplace will overcome the limits of the traditional office workplace and will replace these by the generalized concept of the digital work surface. The prototype of the n-Lightened Workplace is a 45 m^2 room with modular walls that can be replaced by either displays, illuminated spaces or passive spaces with additional "tracked spots" that allow for the individual highlighting of moving objects. With this modular concept we are able to integrate new display technologies as soon as they are available as prototypes. To save energy the nLightened Workplace will use natural daylight as a source of light to backlight large area, passive Displays

(LCD). A combination of a variable diffuser and a LCD panel will be used on a standard window to realise our "Smart Window". All components of the nLightened Workplace, i.e. light sources, displays, daylight elements and passive areas will be controlled by a central system which knows the geometrical distribution of all components and their physical properties such as the maximum luminance. Additionally the light emission from displayed images will be considered. The transmission of the picture information to the respective displays is network based; each display surface is a knot, visible in the network with defined parameters such as size, position, resolution and brightness. The brightness adjustment of the display surfaces is directly controlled through their sources of light.

A central control system enables the dynamic representation of an optimal light situation in space, within certain limits even selectable by the user. The n-Lightened Workplace (Fig. 5) is a research and integration platform for prototype applications, in which work and interaction concepts for concrete applications are developed and evaluated.

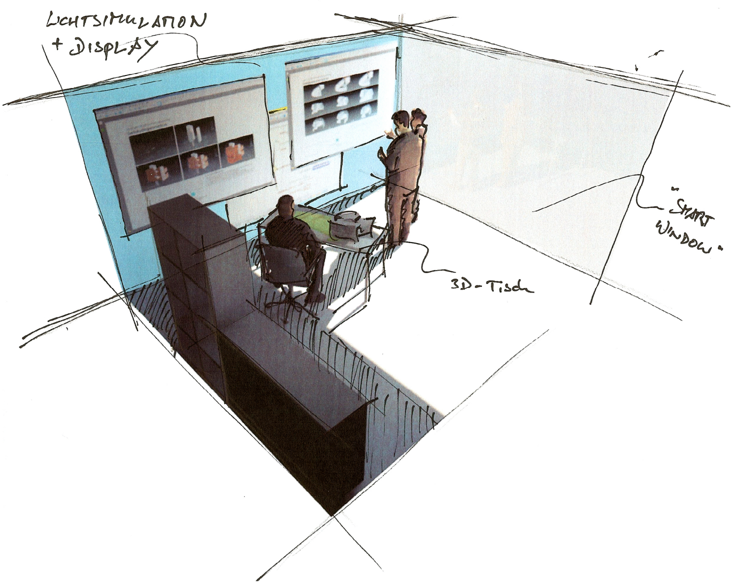

Fig. 5. Design study of the nLightenend Workplace

In nature, the colour of light changes during the day from a reddish warm white in the morning to cold, bluish tones during noon and to red during dusk. If one concludes from the evolutionary adjustment of humans to those colour changes, then it needs to be examined if artificial dynamic lighting has positive effects on humans' wellbeing and performance. Due to the coupling of human rhythms with natural light rhythms positive effects are to be expected with artificial dynamic lighting. "Heliosity" is such a light source which can be dynamically adjusted in both colour and intensity. It is based on five differently coloured LEDs plus one cold-white LED

(Fig. 6). This enables us to tune the colour of light very similar to the changes of natural daylight. If all six LEDs are turned on simultaneously, Heliosity provides a white light with a nearly continuous spectrum similar to that of daylight (Fig. 7). Therefore we expect similar advantages for health and well-being as they are known from sunlight and full spectrum lamps.

By dimming individual colours different light colours can be achieved with a discrete spectrum. The CRI (colour rendering index) with all LEDs turned on is much better than that of standard fluorescent lamps (FL) and the colour gamut is larger than that of conventional LC-displays with LED backlight. The light guide design in conjunction with the use of a *plexiglas* with specialized properties facilitates a smooth and uniform distribution of the emitted light. The *plexiglas* is a transparent, light-diffusing acrylic (PMMA) that exhibits special light-conducting and emitting properties.

Fig. 6. Spectrum of LEDs used in Heliosity

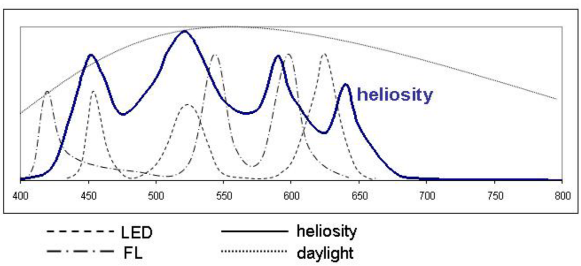

Fig. 7. Spectrum of Heliosity in comparison to daylight, LED-Backlight and fluorescent light (approximation)

5 Future Research Work

Under laboratory conditions we will examine the effects of dynamic light on humans' working performance and health. We suppose that the synchronous light will improve health and efficiency. A desynchronisation might lead to illness and incapacity to act. We need to consider that the bluish-cool white and thus the melatonin suppression during noon could suppress the afternoon low, however, the warm white tones in the evening before the end of work could promote tiredness rather than suppress it. Various colour sequences need to be investigated, compared and evaluated against their effectiveness to enhance productivity. Many cognitive functions of humans are subject to the so-called Basic Rest Activity Cycles (BRACs). Natural light changes from light to shade caused by passing clouds occur in a similar time range as BRACs. It needs to be examined whether the reproduction of the cloud play by artificial lighting can stimulate cognitive functions. To investigate our hypothesis we are currently installing a large area LED display on the ceiling which will enable us to simulate various colour and light variations.

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