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Ambiguities regarding the relationship between office lighting and subjective alertness: An exploratory field study in a Dutch office landscape

J. van Duijnhoven[a,d,*], M.P.J. Aarts[a,d], A.L.P. Rosemann[a,d], H.S.M. Kort[b,c]

[a] Eindhoven University of Technology, Department of the Built Environment, Building Lighting Group, P.O. Box 513, 5600 MB, Eindhoven, the Netherlands
[b] University of Applied Sciences Utrecht, Research Centre for Innovations in Health Care, P.O. Box 12011, 3501 AA, Utrecht, the Netherlands
[c] Eindhoven University of Technology, Department of the Built Environment, Building Healthy Environments for Future Users Group, P.O. Box 513, 5600 MB, Eindhoven, the Netherlands
[d] Intelligent Lighting Institute, Eindhoven University of Technology, P.O. Box 513, Eindhoven, the Netherlands

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ABSTRACT

The current field study investigated the ambiguities regarding the relationship between office lighting and subjective alertness. In laboratory studies, light-induced effects were demonstrated. Field studies are essential to prove the validity of these results and the potential recommendations for lighting in future buildings. Therefore, lighting measurements and subjective health data were gathered in a Dutch office environment. Health data was collected by questionnaires and includes data on functional health, wellbeing and alertness. Multiple general, environmental, and personal variables were identified as confounders for the relationship between light and alertness. For six out of the total 46 participants a statistically significant correlation was found between horizontal illuminance (E_{hor}) and subjective alertness. Further research needs to incorporate a larger sample size and more potential confounders for the relationship between E_{hor} and alertness. Further research including these recommendations may explain why certain people respond to light while others do not.

1. Introduction

Light entering the eyes reaches the rods and cones on the retina which then stimulate vision. In addition to these two photoreceptors (i.e., rods and cones), a third photoreceptor was discovered approximately fifteen years ago [1], the so called intrinsically photosensitive retinal ganglion cell (ipRGc). These ganglion cells capture light (i.e., effective irradiances) which has entered through the eyes and these cells initiate processes in both the **Image-Forming** (**IF**) and **Non-Image-Forming** (**NIF**) centres of the brain. Previous studies indicated effects of light on human's health and well-being [2–5]. These effects can be acute (short-term) or circadian (long-term) effects. Acute effects are, for example, alerting effects or distraction due to glare or flicker. Circadian effects are caused due to exposure to a lighting condition for a certain period of time and are, for example, the regulation of hormones or the organisation of the biological clock. The production of the hormone melatonin is one example of a hormone which is influenced by light exposure. Zeitzer et al. [6] developed dose-response curves in order to determine a relation between light and melatonin. A mismatch between light exposure and individuals day/night rhythm can lead to a disrupted circadian system [3]. This disruption is associated with poor health and a lower work performance [3]. In addition, office lighting is often demonstrated to directly affect work performance [7–9]. Demonstrated direct and indirect effects of (office) lighting on health and work performance highlight the importance of the *most appropriate light exposure at the right moment of time*.

An individual's daily light exposure consists of contributions from daylight and electric light sources. One of the current challenges is to determine the individual's need for light to enhance their health. Since individuals differ in experiences, sensitivity, and preferences, each individual has different responses to light exposure [10]. Therefore, it is recommended to investigate the relationship between light and health based on **personal lighting conditions** [11,12]. The relationship between (either general or personal) light exposure and occupational health is investigated in multiple studies [7,13–16]. The experiments took place in laboratories, in simulated office rooms, or in realistic office buildings. The majority of the experimental studies included in the review of van Duijnhoven et al. [17], was performed under laboratory conditions whereas employees may react and behave differently in a real work environment. The actual effects of office light exposure on an employee's health need to be investigated and validated in real office environments.

In order to investigate the relationship between office lighting and any outcome measure (e.g., occupational health, subjective alertness),

* Corresponding author. Eindhoven University of Technology, Department of the Built Environment, P.O. Box 513, 5600 MB, Eindhoven, the Netherlands.
E-mail address: J.v.duijnhoven1@tue.nl (J. van Duijnhoven).

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the lighting environment needs to be identified. Identifying a lighting environment comprises multiple lighting measurements. Illuminances and correlated colour temperatures are the most common measures to map a certain lighting situation [17]. Besides these two light parameters, the CIE proposed a protocol for describing lighting in an indoor environment including people, context, lighting systems and components, room surface light levels and distribution, task details, task area light distribution, high-luminance areas, modelling, colour appearance, and dynamic effects [18]. In addition, light measurements can be performed continuously (once per set interval, e.g. 1 s or 1 min) or at specific moments during the day. In addition, measurements can be performed person-bound or location-bound [11]. Furthermore, light measurements can be performed inside or outside.

To the authors' knowledge and based on the literature review [17], this is the first field study which investigates the relationship between personal lighting conditions lighting and **subjective alertness** (**SA**), both measured at the same timestamp. No intervention to the lighting system was introduced in this study. All participants were exposed to their regular lighting environment.

The study described in this research paper included continuous location-bound measurements to identify the indoor lighting environment and questionnaires to gather information about the health outcome measures (e.g., SA). The study was conducted as part of a larger research project investigating the potential impact of office lighting on occupational health in office landscapes. The aim of this experiment was to investigate the ambiguities regarding the relationship between office lighting and SA. It was expected that the investigation of this relationship in a field study would be challenging due to multiple potential **confounders**. Another aim of this study was to search for aspects which potentially explain the relationship between **horizontal illuminance (**E_{hor}**)** and SA in order to be taken into account for future (field) studies.

All considered variables in this study were categorized into **general**, **environmental**, and **personal variables**. General variables consisted of day and time of the day, environmental variables were light, temperature and relative humidity, and the personal variables were user characteristics, self-reported sleep quality and health scores. It was expected that SA was related to all three types of variables. In addition, since individuals respond differently to changes in lighting conditions, it was expected that the correlation between SA and E_{hor} differed between the participants (i.e., that the correlation was significant for a percentage of the participant sample size). Finally, it was expected that differences in correlations (i.e., between SA and E_{hor}) between the participants could be explained through the personal variables.

2. Methods

The field experiment was performed during one 5-day work week in May 2016 in a two-floor office building in the Netherlands. The weather conditions varied from an overcast sky on Monday, Tuesday, and Wednesday towards a clear sky on Thursday and Friday. The dawn and dusk times were around the local times 5:30 and 21:45 respectively. The local times related to the daylight saving time in the Netherlands (March, 27th till October 30th, 2016). The office hours of all the participants fell in this daylight period.

2.1. Office environment

The study location was a two-floor office building in the West of the Netherlands (Hendrik-Ido-Ambacht) (see Fig. 1). This building was renovated in 2015 and transformed from a closed structure to an open structure with office landscapes. This office transformation is part of the new Flexible Working Arrangements (FWA) [19]. Companies increasingly support this working practice in order to improve employee's productivity at work. The office building of the current study consists of two floors, each consisting one large office landscape. On the first floor

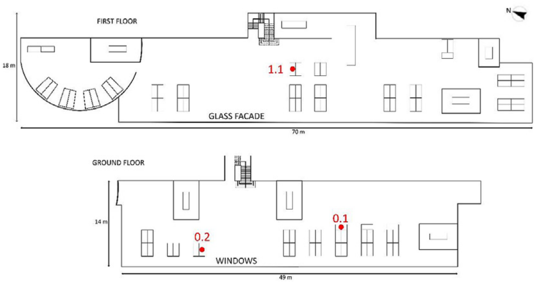

Fig. 1. Floor plans office building. The red dots indicate the three measurement reference locations (0.1, 0.2, and 1.1). Participants were able to work at all the desks – except the reference desks – displayed in the floor plan. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

there is one separate office landscape on the North side and there are four office spaces enclosed with glass throughout the whole office building. The first floor contains 52 desks and the ground floor contains 31 desks.

2.2. Office lighting

The west façade on the ground floor contained daylight openings without sun shading devices. In contrast, on the first floor, the building façade was more open and this façade consisted of sun shading devices (see Fig. 2 and Fig. 3). It was not recorded when the shading devices were open or closed.

In addition to the presence of daylight, electric lights were installed. The office landscapes were lit by dimmable suspended luminaires (Prolicht, Glorius, Ø1400 7x14//24 W DALI, see Fig. 4) and dimmable LED spots (Quadro LED reflector 31 W 2100 l m 3000 K or Quadro LED Reflector 53 W 2400 l m, see Fig. 5). The electric lighting in the office landscapes was on during office hours and dimmed based on the amount of daylight. The dimming levels (0–100%) were logged in the lighting system. There were no desk lights available at the desks.

Most lighting recommendations for Dutch office buildings are horizontally focused [20]. In earlier times, when most offices were paper-based, it was important to focus on the horizontal light levels. Recently, the vertical lighting conditions (e.g., vertical illuminance) are more important due to the digital world the office workers are currently working in. However, due to practical reasons, only E_{hor} at desk level were measured in this study.

In order to gather continuously measured E_{hor} at all work places throughout the office building, the non-obtrusive method (**Location-Bound Estimations, i.e. LBE**) developed by van Duijnhoven et al. [11,12] was applied. This method consists of **reference locations** at which continuous measurements are performed and predictive models between the reference locations and all other workplaces (i.e., **outcome locations**[11]) inside the office in order to estimate the lighting conditions at all workplaces. Between two and four **relation measurements** (between reference and outcome locations) [11] were performed per outcome location to create the predictive models. During the relation

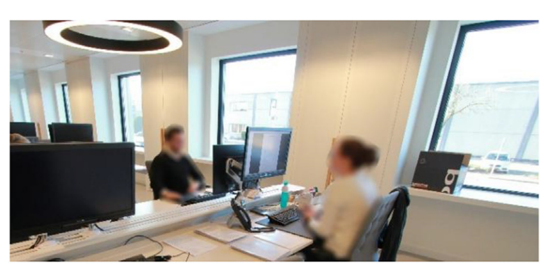

Fig. 2. Facade ground floor (windows).