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Effects of Light on Attention of Fulltime Daytime Workers – A Laboratory Study

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Abstract

In addition to its impact on our circadian rhythm, researchers have investigated also alerting effects of light. While effects of light on sleep-wake rhythm and hormone cycles are well proven, evidence for effects on attention is less clear. Circadian effects of light can be best predicted by the activation of ipRGCs within the retina. Hence, we wanted to test the hypothesis whether an increase in activation leads to an improvement of attention during the day. Here we present a laboratory study that focused on alerting effects of light on fulltime daytime workers. We included a workday-like exposure duration and lighting scenes that comply with regulations for office workplaces. It was found that besides attention, participants' mood and perceived well-being were also affected. Contrary to our hypothesis, the results for different correlates of attention were best under lighting with the least activation of ipRGCs.

Index Terms: *NIF Effects, Alerting Effects, Attention, Light*

1 Introduction

In Germany, regulations for lighting at workplaces are defined by the Workplaces Ordinance and the associated Technical Rule ASR A 3.4 [5]. There, a minimal horizontal illuminance of 500 lx at desk level in the primary working area and a vertical illuminance of at least 175 lx are demanded. These regulations primarily focus on the assurance of a proper vision at work in order to complete the given working tasks. However, by now it is well known that light also elicits effects beyond vision. On one hand, long-term effects on the human circadian system, e.g. sleep-wake cycle and hormone cycles could be shown. On the other hand, research on acute effects on attention, mood and working performance gains more and more interest. Until now, several laboratory studies investigating the impact on attention have been conducted [14, 16]. Those studies show a great variability in study designs, lighting scenarios and correlates of attention that were investigated. In general, studies were conducted either during the evening and night or during the day. In addition, some researchers focused on monochromatic light exposure, while others considered polychromatic white light. Concerning correlates of attention, three major groups of studies can be identified. In most studies subjective scales were used in order to gain knowledge about the perceived state of participants. Here, the Karolinska Sleepiness Scale (KSS) is most frequently used [14, 7]. Further information about acute effects are gathered by including psychomotor tasks. In general, these require a response to different types of stimuli. The complexity of the tasks and the exact implementation regarding types of stimuli, task duration or inter-stimulus intervals differs remarkably. However, certain types of tasks are used frequently, such as the Psychomotor Vigilance Task (PVT), the Go-NoGo-Task (GNG-Task) and the NBack Task. In addition, some studies also include physiological correlates of attention, such as heart rate variability, skin conductance or several EEG parameters. Although comparison of studies is impeded by the variations in study design, several research groups tried to narrow down the existing evidence by reviewing the body of research [1, 7, 14, 17]. Overall, some studies found effects of light on the attention, while others could not confirm them. Therefore, evidence for acute alerting effects is much smaller than for circadian effects. In general, this also is evoked by difficulties in study designs, such as too small sample sizes or lighting scenarios that are far away from real-life lighting. Still, in 2020 Brown published a metastudy in which he stated that effects on attention could be best predicted by the so-called melanopic equivalent daylight illuminance (MEDI) [2]. This value describes the activation of the photopigment melanopsin within a specific type of receptor cells of the retina (ipRGCs – intrinsically photosensitive retinal ganglion cells). It equals the illuminance that a D65 light source must have to elicit the same activation as the light source of interest. Those receptor cells are connected to several brain regions that control our circadian rhythm, as well as mood and attentional state. Therefore, they are thought to mainly mediate non-image forming (NIF) effects of light. The importance of the MEDI was further underlined in 2022 by Brown et al. who published recommendations for indoor light exposure [3]. For daytime levels, a MEDI threshold of 250 lx was introduced. Most of the existing literature on alerting effects of light does not explicitly focus on a variation of MEDI. Furthermore, many studies only include short exposure durations that are not easily translatable to real-life working conditions of fulltime daytime workers. Since especially ipRGCs are known to display a different temporal behavior than cones, it is possible that several effects can only be seen after longer exposure. In addition, regulations for lighting at workplaces should be considered in order to facilitate the transferability to real-life settings.

Our work was an attempt to address these issues by executing a laboratory study that includes a workday-like exposure duration, different lighting scenes that do all comply with existing lighting regulations for workplaces and a sample size of 42 participants.

2 Methodology

In the laboratory study, we included three lighting scenes that differed in their MEDI. For the first scene (wl – warm low) a color temperature of 2700 K and a horizontal illuminance of 500 lx at desk level was chosen. In order to increase the MEDI, the spectrum was then changed to a color temperature of 5400 K for the second lighting scene (cl – cool low). In order to further increase the MEDI, the spectrum was not changed, but the horizontal illuminance at desk level was set to 1500 lx (cb – cool bright) . Figure 1 shows spectra and MEDI measured vertically on the anterior edge of the desk at a height of 120 cm. As shown there, changing the spectrum from wl to cl led to a 2.1 fold increase in MEDI, while increasing the illuminance gave a 2.8 fold increase. Thereby, the MEDI could be increased by a factor of approximately 5.9 from lighting scene wl to cb.

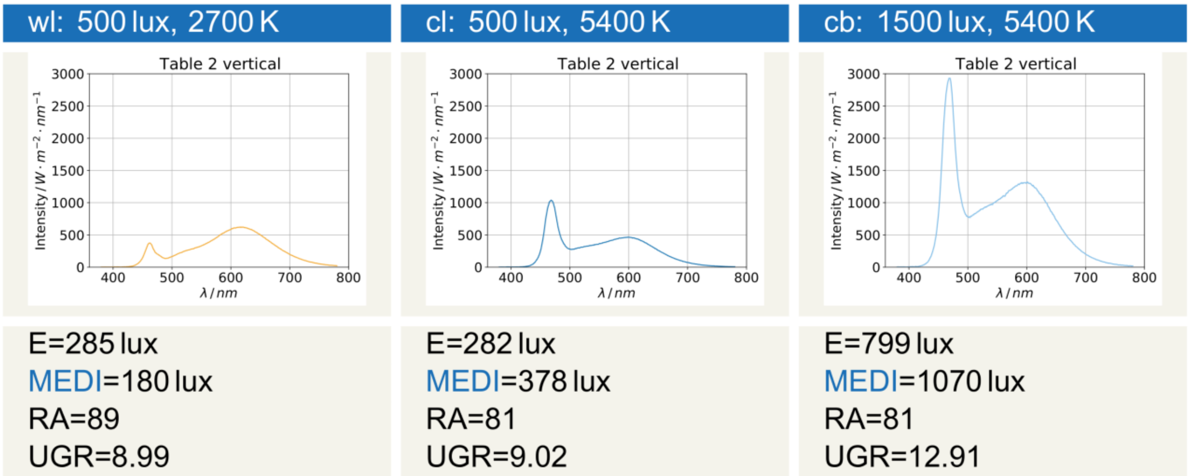

Figure 1: Information about lighting scenes.

To examine alerting effects of light, a combination of subjective scales and psychomotortasks was used. In general, the KSS, a PVT, a combination of a GNG-Task and a 2-Back-Task, as well as a simple GNG-Task was included. In addition, participants completed the NASA-Task-Load-Index, as well as several visual analogue scales concerning their impression of the lighting and room and their mood state. Detailed information about scales and tasks and a discussion why they were chosen can be found elsewhere [10].

In general, we aimed at investigating the effects on different types of attention, lighting appraisals and mood. All tasks were completed six times a day, as shown in Figure 2.

Between test phases, participants completed different types of work tasks that were either chosen to simulate office work or motor work. These were also analyzed separately but were added particularly to ensure that attention had to be maintained over the full course of the day. Office work included text comprehension and typewriting, while in phases of motor work either constructs of building blocks on an elastic band had to be build or participants had to build a box from paper by cutting, drawing a pattern and assembling the box. Types of work were randomized in such a way that half of the participants started with the office work (A) in the mornings, while the other half started with motor work (B).

All participants completed four session days on which lighting scenes were shown in a randomized manner. Lighting scene cb was repeated twice. In addition, before the start of the first session, an introduction day was included. On this day, all tasks and work types were practiced in order to reduce possible learning effects. Figure 3 shows a photograph and a luminance image taken in the laboratory room.

9:00	Welcome
9:15	Test Phase 1
9:50	Office Work 1
10:45	Test Phase 2
11:20	Office Work 2
12:15	Test Phase 3
12:40	Lunch Break
13:20	Test Phase 4
13:55	Motor Skills 1
14:50	Test Phase 5
15:25	Motor Skills 2
16:20	Test Phase 6
16:45	Farewell

Figure 2: Protocol of a session day.

Figure 3: Luminance image and photograph of laboratory room.

In addition, several covariables were taken into account during the design of the study. Therefore, exclusion criteria were applied in order to obtain a more homogeneous group of participants. Only participants under the age of 35, who were no extreme chronotypes (as assessed by D-MEQ), did not show an explicitly bad sleep quality (as assessed by PSQI [3]), did not smoke or consume coffee, black tea or alcohol in an extensive manner and passed the Ishihara color blindness test were included. Other covariables, such as sex, order of working phases and whether participants were caffeine consumers could be included in the analysis.

During the whole session block, participants wore Actiwatch Spectrum Devices (AWSDs) [7]. Those include three different sensors in the blue, green and red part of the spectrum. From these detectors, AWSDs also calculate illuminance values. In accordance to Price et al., we used the signal from the blue and green detectors in order to provide information about exposure in terms of MEDI [8].

2.1 Statistical Analysis

Data of test and work phases was analyzed using linear mixed models (LMMs). In general, these enable the inclusion of several parameters simultaneously, while also providing the opportunity to account for the within-subject design of the study. Hence, the participant ID (PID) was included as random intercept. Lighting Scenes (*case*) and Time Points (*time*) were used as fixed effects in every model. Further variables were included as fixed effects, whenever this inclusion led to an improvement of the so-called Akaike Information Criterion (AIC). This quantity described the information lost by a given model. Hence, the model with the smallest AIC was chosen in order to provide the analysis that best describes the data collected in the experiment. Optional fixed effects included the session day, sex, order of working phases, caffeine consumption and chronotyope (*chron*). Furthermore, an interaction term of lighting and time points could be included if this led to an improvement of the AIC. For every parameter of the tasks and scales, a new model was built. Model assumptions of LMMs include normal distribution of residuals, as well as homogeneity of variances. Both were examined by visual inspection. Normal distribution was investigated by histograms, while for homogeneity of variance scatter plots of fitted against residual values were used. Here, data points should not display a strong pattern.

Besides continuous parameters, such as the mean reaction time during the PVT, also ordinal parameters, such as the KSS score or lapses, were investigated. However, these were also analyzed using LMMs. Although also other possibilities, such as proportional odd models were considered, these were rejected in favor of LMMs because the would require similarly occupied classes. On one hand we wanted to avoid a classification after acquiring the data, on the other hand classes would have to be built in such a way that they were similarly occupied which is why the meaning of classes could be questioned. Hence, LMMs were chosen and residuals were found to be generally normally distributed and scatter plots of residuals against fitted values did not display strong patterns besides the pattern introduced by the ordinal manner of the variable.

3 Results

3.1 Light Exposure

Vertical illuminance and MEDI was measured on every workplace in the laboratory room. Workplaces for motoric work were generally brighter because they did not include a monitor. However, differences between the two motor and office workplaces were within the range of uncertainty of the spectroradiometer.

Differences in light exposure as measured by AWSDs were found to behave in the expected manner, as shown in Figure 4.

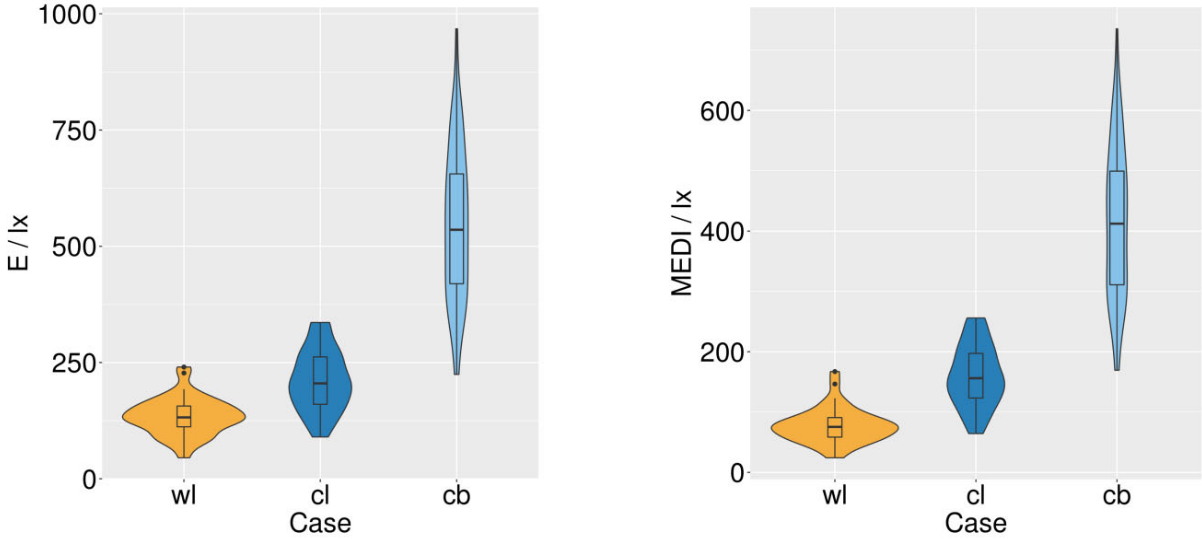

Figure 4: Average illuminance and MEDI during session days, measured by AWSDs.

However, illuminance values between cl and wl differed more than expected. This could be explainable by differences in the sensitivity curve used for the calculation of illuminance values by the AWSD and the exact V(λ) curve, as discussed by Figueiro et al. [4]. AWSDs are likely to overestimate light in the blue range of the spectrum.

3.2 Test Phase – Mean reaction time of PVT

As an example, results for the mean reaction time (RT) of the PVT will be presented. The model that best described the measured data included the following variables:

$$\text{Mean RT} \sim \text{case}+\text{time}+\text{day}+\text{sex}+(1|\text{PID})$$

As already mentioned, the PID was included as random intercept. Predicted values of the model are shown in Figure 5.

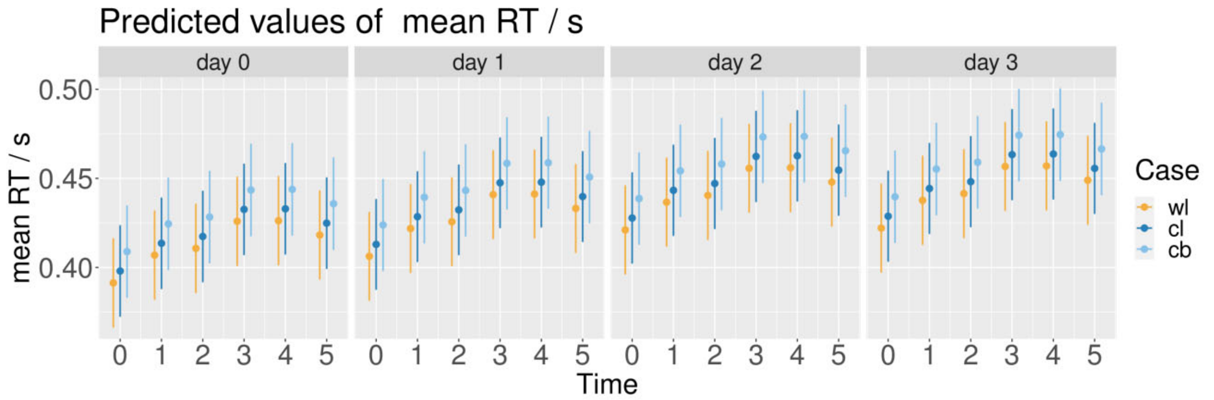

Figure 5: Predicted values for mean reaction time in PVT. Only differences in the parameters case, time and day are displayed.

Here, it is easily seen that reaction times increased during the day until time point three, were approximately constant on time point four and then decreased during the last test phase. In addition, reaction times increased from day one to three and did not change significantly again on day four. Regarding the effect of the lighting, it is crucial that reaction times were the lowest under the warm lighting and were significantly increased in both cold lighting scenes. Indeed, post-hoc testing revealed a significant difference between all lighting scenes.

3.3 Test Phase – KSS Score

KSS Scores were best predicted by the following model:

KSS Score ~ case+time+day+(1|PID)

As shown in Figure 6, sleepiness was lower for the warm lighting. However, post-hoc testing did not reveal significant effects. Regarding the course of the day, sleepiness increased from time zero to one, while it decreased slightly until time point three. For time points four and five a significant increase in sleepiness was seen, while for the last test phase sleepiness was slightly reduced again. In comparison to day zero, sleepiness values were significantly increased on days two and three.

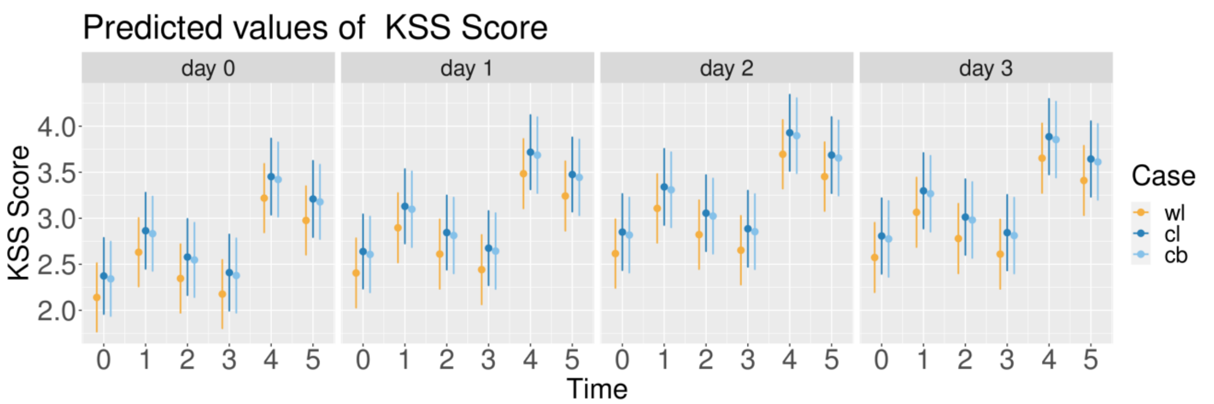

Figure 6: Predicted values of KSS scores. Only differences in the parameters case, time and day are displayed.

3.4 Test Phase – Lighting Appraisals and Mood

Figure 7 shows violin plots of the results of two different scales considering lighting appraisals. It is shown that the cold bright lighting was perceived as too cold and unnatural. In addition, several scales were also analyzed using LMMs. These included:

- Distraction
- Exhaustion
- Weariness
- Comfort

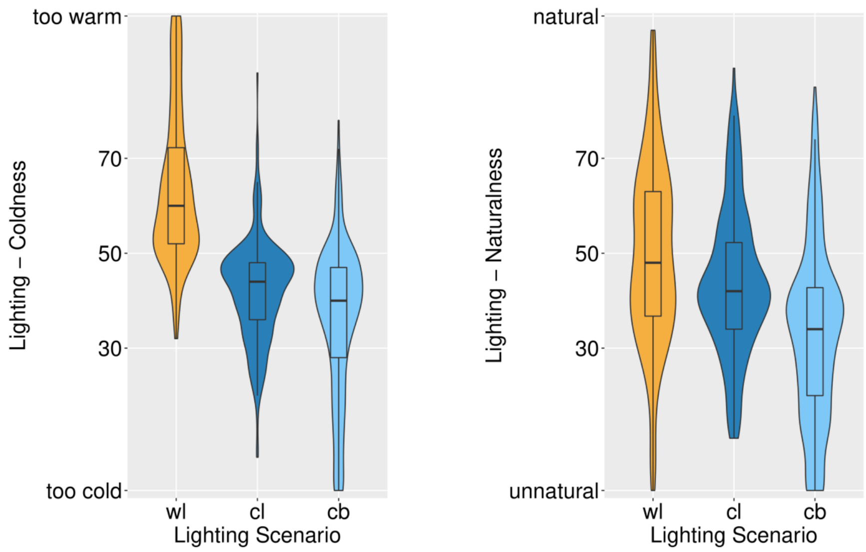

Figure 7: Ratings for coldness and naturalness of lighting scenes.

It was found that the warm lighting was perceived as significantly less exhausting, distracting and more comfortable than the cold bright lighting.

In general, parameters of test phases did either not show significant differences regarding lighting, or results were best under warm lighting.

3.5 Work Phases

For the parameters of work phases, no significant differences induced by the lighting scenarios were seen, except for a deviation in drawing patterns on boxes.

4 Discussion

Results of work and test phases were not in accordance with the hypothesis that an increase in MEDI would lead to improvements of attention. For most parameters the warm lighting with the lowest MEDI led to the best results or parameters did not show differences regarding lighting. Furthermore, also lighting appraisals and perceived comfort and mood were best under warm lighting.

If ipRGCs also have the ability to influence our limbic system, it is understandable that such parameters may be affected by the present lighting in a similar manner as attention. In addition, it is possible that mood or comfort may in turn influence the attention of people. In 2011, Rautkylä et al. provided a model to describe the link between light exposure and brain mechanisms. Here the authors also included the limbic system and strongly recommend to take into account emotional components when investigating alerting effects of light [9].

In addition, there has been research on the effects of lighting on mood, workplace satisfaction and comfort or pleasantness [12, 14, 15]. However, results are partly contradictory and a full picture is still to be drawn. Nevertheless, it is quite clear that lighting has the potential to elicit changes in such parameters which may also in turn affect attention. Possibly, also intrinsic motivation may be influenced by light which may lead to improvements or impairment of attention [6].

The hypothesis that an increase in MEDI leads to an improvement of attention mainly considers the idea that a higher MEDI leads to an increase in ipRGC activation that in turn supports attention. However, even if this effect is evoked by either lighting scene cl or cb in this study, possible positive effects may be counteracted by negative effects of poorer mood and an increase in discomfort. Especially for long exposure durations, perceived discomfort may lead to severe impairments of test results. Furthermore, it is possible that the young study population that was included in the study can more easily compensate a lack of ipRGC activation than an increased feeling of unpleasantness.

Regarding the course of the day, it is striking that results improve during the last test phase for almost all parameters. It is suggested that this is a ‘going-home-effect’ meaning that participants have a higher intrinsic motivation due to the fact that they can leave the laboratory after this test phase. Effect of the lunch break were only seen in some parameters.

5 Conclusion

In general, the hypothesis that an increase in MEDI leads to an improvement of attention during the day could not be supported by the study results. In future studies, effects on mood and comfort should be equally included in the study designs and addressed by questionnaires. For real life workplaces our results show that not only an increase in MEDI, but also the effects on mood and comfort should be considered when changing lighting at office workplaces. Hence, more pleasing lighting solutions are favorable. These may include the possibility for employees to control brightness, spectral composition or proportion of direct and indirect lighting to increase overall acceptance and comfort.

Overall, further studies that equally consider the interplay of effects of light on attention, mood and well-being should be executed in order to increase our existing knowledge and enable the design of new lighting solutions that support people's attention but also well-being at work.

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