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Effects of Light on Attention during the Day: Spectral Composition and Exposure Duration

Hannah Rolf [1]*, Ljiljana Udovicic* [1]*, Stephan Völker* [2]

[1] Federal Institute for Occupational Safety and Health (BAuA), Dortmund, Germany

[2] Technical University of Berlin (TUB)

Abstract

The aim of the study is to investigate effects of light on attention during the day. In particular, changes in spectral composition and prolonged exposure durations are analyzed. The study design was developed to explicitly refer to working days of fulltime daytime workers and therefore increase the transferability to real-life work situations. A combination of subjective scales and psychomotoric tasks is used to address different types of cognitive processes and get a holistic picture of the attentional state. In general, this study contributes to a more precise description of alerting effects of light that may lead to lighting designs that actively support employees at their workplace in the future.

Index Terms: Workplace Lighting, NIF Effects, Attention, EDI

1 Introduction

Since the discovery of the intrinsically photosensitive retinal ganglion cells (ipRGCs) containing the light sensing photopigment melanopsin, there is growing interest in the research field of non-image forming (NIF) effects of light. This terminology refers to light-induced effects that are not contributing to vision, but rather influence a diversity of ongoing processes in our body. NIF effects can be further distinguished into long- and short-term effects. Long-term effects appear within the timeframe of several days or weeks. They are also known as circadian effects, since they can alter the human circadian rhythm. This can be manifested as changes of sleep rhythm, secretion of hormones, course of body temperature and many others. On the other hand, light can also cause short-term effects that appear within minutes or hours after exposure. These are mainly referred to as effects on the alertness and can be manifested as psychological, such as a subjective decrease of sleepiness, but also physiological effects, such as an increase in heart rate or alternations in EEG-activities.

Numerous studies have been already carried out to investigate NIF effects on humans. Although some results could be reproduced and are widely accepted by the community, there are contradictory statements and a clear, holistic picture of NIF effects is still to be drawn. Since it is known that light can influence alertness, it is not surprising that researchers are also trying to find optimal workplace lighting supporting employees and increasing well-being and productivity at the workplace. However, most studies use designs that are not easily transferable to real-life working conditions. The presented study is an approach to fill this gap by creating a study design that focuses on fulltime daytime workers.

2 Overview of relevant variables

As already mentioned, existing studies investigating NIF effects of light show different and partially conflicting results. A possible reason is the variety of variables that were taken into account. Independent variables often characterize the light that is used, such as illuminance, spectral composition, color temperature, directionality etc. In addition, other variables such as time dependence (exposure duration, time of day) can be varied. Generally, it is striking that results between studies differ and are even contradicting, as shown in a review by Souman et al. [1]. However, Brown et al. showed that the melanopic equivalent daylight illuminance (MEDI) is a god predictor for circadian effects, such as melatonin suppression [2]. We therefore assume that this may also be true for alerting effects of light. To systematically vary the MEDI, alternations in spectral composition and illuminance are used. These are common quantities to be varied in studies within this research field, as described in Rolf et al. [3] (to be published).

Light scenes in some laboratory studies do not comply with the OSH regulations for lighting at workplaces, leading to results hardly transferable to real-life applications. Since in this study every light scene fulfills the requirements for workplace lighting, it is possible to investigate whether light variations within these requirements can improve alertness.

Dependent variables are determined by the type of study being conducted. Circadian rhythms are often assessed by salivary melatonin and sleep/wake cycles, whereas attention is mostly evaluated by combinations of subjective scales and psychomotoric tasks. A huge variety of different task and task parameters can be found in the literature [4]. This also partly explains why results often differ and are rarely comparable. In addition, the acceptance of presented light scenes is often assessed by questionnaires.

When performing a study, there are many covariables that must be taken into account. Some of these can be controlled by choosing participants that fulfill specific criteria. On one hand this leads to a more homogenous group and increases significance of small effects, on the other hand it excludes some people, whose reaction to the light scenes also is of great interest. If effects should be applied in real-life workplaces, follow-up studies are needed to ensure that possible positive effects also arise in other groups, or at least no negative effects appear. Criteria applied for the participation in the presented study are shown and explained in Tab. *1*.

Parameters	Criteria	Description
Age Language	18-34 German	Opacity of eye lenses German task descriptions
Color Vision Sleep Quality Chronotype	Ishihara Test PSQI D-MEQ	Altered color perception Sleep Deprivation influences light effects Same circadian phase
Change in Time Zones Nicotine Coffee & Tea Alcohol	Not within last month Non-Smokers < 4 Cups No excessive consume	Possible jetlag No breaks Strong habituation effect Long-term influence on attention

Tab. 1: Overview on criteria used for in- or exclusion of participants. The Ishihara Test must be passed without errors or missing answers. PSQI score must not be greater than five. Extreme chronotypes are excluded.

In addition, there are covariables that refer to the current state of a participant. These include for example mood, sleep duration, sleep efficacy or light history (see section 9). Fig. *1* gives an overview on dependent, independent and covariables that are considered in this study.

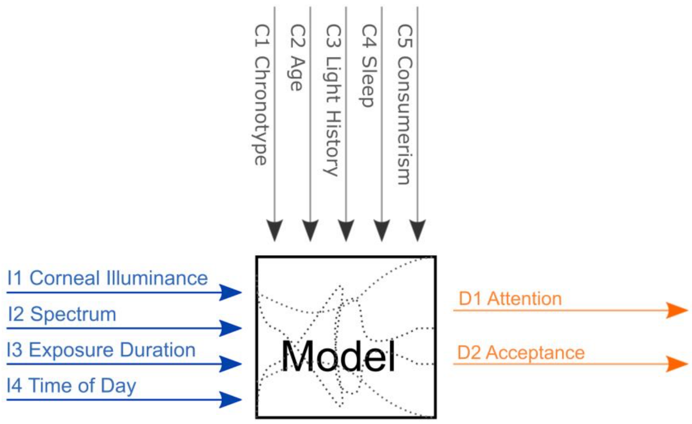


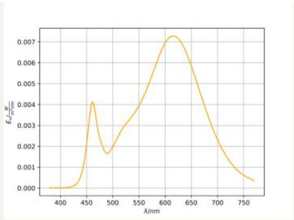
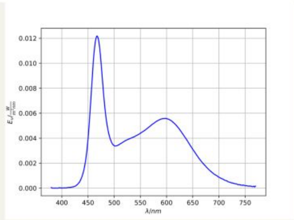
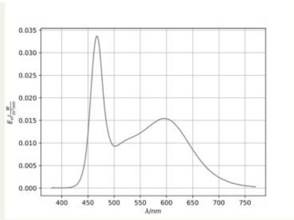
Fig. 1: Overview on independent, dependent and covariables that are considered within this study.

3 Independent variables – spectral composition and illuminance

As mentioned before, the aim of this study is to investigate NIF effects of light, mediated by the melanopsin containing ipRGCs. A systematic variation of melanopic stimulation is achieved by adjusting the spectral composition of light, as well as the illuminance. The activation is expressed as the vertical MEDI ($MEDI_v$) at eye level when seated (120 cm), as defined in CIE S 026:2018 [5].

The first light scene (LW: Low Warm) has a horizontal illuminance at table level of 500 lx (E_v =360 lx) and a color temperature of 2700 K. This results in a $MEDI_v$ of 162 lx. In two further scenes the activation of melanopsin is enhanced. In the second scene

(LC: Low Cool) the color temperature is set to 5700 K, increasing the $MEDI_v$ by a factor of 2.14. In the third scene (HC: High Cool) the illuminance is additionally increased to 1500 lx at table level (E_v = 1000 lx) leading to an increase of $MEDI_v$ by 2.77. In summary, the $MEDI_v$ varies by a factor of 5.93 between the first and the third light scene (see Tab. 2).

LW: 500 lux, 2700 K	LC: 500 lux, 5400 K	HC: 1500 lux, 5400 K
		
E_v = 356 lux $MEDI_v$ = 162 lux RA = 89	E_v = 362 lux $MEDI_v$ = 347 lux RA = 81	E_v = 1003 lux $MEDI_v$ = 963 lux RA = 81

Tab. 2: Description of light scenes.

As the presented study uses a within-subject design, all subjects participate in each light scene. In addition, the third light scene is doubled as a control. Therefore, as shown in Tab. 3 one block consists of four experimental sessions and an introduction day, on which the procedure is being explained and tasks are practiced. The order of light scenes is randomized between participants.

	Mon	Tue	Wed	Thu	Fri
Week 1					Introduction
Week 2		Session 1		Session 2	
Week 3		Session 3		Session 4	

Tab. 3: Overview of one study block, consisting of an introduction and four session days. The order of light scenes is randomized between participants.

4 Dependent variable – Attention

Since this study aims to investigate effects of light on attention, this term must be defined within the scope of this project. Regarding the literature, it is striking that different terms, such as alertness, attention, arousal and vigilance are frequently used without specifying their meaning in the given context. This section explains different concepts of attention and clarifies how the terms mentioned before are going to be used within this paper.

Attention can be defined as a fundamental function, on which cognitive processes are built [6]. Different models of attention have been developed in psychology. Depending on the underlying processes that are used to create models, these are referred to as 'clinical' or 'cognitive'. While in cognitive models the distinguishing criteria are based on ongoing cognitive processes, clinical models refer to the neurobiological background behind the underlying processes. In addition, there are approaches to combine cognitive and clinical models to get a more holistic description of the ongoing processes [7]. One way to define different forms of attention is to relate to the time period in which attention is observed. The overall ability of a person to litigate information during the day is referred to as tonic alertness. This includes for example the sleep-wake-cycle, as we are significantly more alert during daytime, when awake. On the other hand, phasic alertness refers to a much shorter time period and describes the ability to react to the reception of a given stimulus [8]. In most literature, the definition of arousal is very close to the described understanding of tonic alertness, describing the overall state of process-ability of information.

Apart the given time period, also the complexity of the reaction to a stimulus can be used to define different forms of attention. Expanding the ideas of van Someren and Brouwer [7], who intended to create a joined clinical and cognitive model, Sturm defined two different dimensions of attention [9]. The intensity dimension includes basic functions of attention. On the other hand, the selectivity dimension refers to more complex processing operations. As shown in Tab. 4 these two dimensions are further distinguished into different sectors.

Dimension	Sector	Description
Intensity	Alertness (phasic, tonic)	activation of attention (with, without specific stimulus)
	Sustained Attention	long-lasting attention high proportion of targets
	Vigilance	long-lasting attention low proportion of targets
Selectivity	Selective or Focused Attention	focus on specific stimuli in presence of dictractors
	Switching Function	visuo-spatial shift of attention
	Divided Attention	allocation of attention to different tasks

Tab. 4: Overview on Strum's model of attention [8].

The two functions can be associated to different brain regions, although a complete separation is not observed. The intensity function includes phasic and tonic alertness, which is understood as the activation of attention with or without a specific stimulus. Furthermore, sustained attention and vigilance can be assigned to this dimension. Different approaches for the differentiation of these sectors can be found in the literature. According to Sturm sustained attention refers to long-lasting signal detection with a higher proportion of targets, while the proportion is much lower when vigilance is required. Some authors include the duration of a task to distinguish between those sectors, others do not distinguish between these terms [10].

The selectivity dimension includes three different sectors. Selective or focused attention describes the ability to isolate a relevant stimulus and maintain that focus, even when distractors occur and other cognitive processes are proceeded in parallel. A spatial shift in attention is described by the second sector. Visuo-spatial selective attention refers to the so called 'orientation reaction' which includes an overall increase in attention, as well as the alignment of attention to a specific stimulus. This function therefore requires the disengagement from the current stimulus, the shift of the focus and the engagement to a new stimulus. It is also referred to as switching function [6]. If a redirection of attention is required regularly, this is also referred to as alternating attention. The third sector, 'divided attention', describes the allocation of attention to different processes or stimuli. The frequency in which a shift of attention is required determines whether alternating or divided attention is needed. Rockstroh defines a temporal limit of one second [6].

4.1 Operationalization of attention – test phase

In order to operationalize attention, a combination of subjective scales and psychomotoric tests is used. The order of chosen tasks is shown in Tab. *5*. Since test phases are repeated six times each day, the duration of each task is limited in such a way that a full test phase does not exceed 30 minutes.

Task	Quantity	Parameters
KSS	Sleepiness	9 point likert-type-scale
PVT	Sustained Attention	average reaction time 10% fastest / slowest reactions lapses
2Back/GoNoGo	Working Memory Alternating Attention	Number of correct reactions avergae reaction time 10% fastest / slowest reactions lapses
GoNoGo	Inhibitory Potential	average reaction time 10% fastest / slowest reactions mistakes
NASA-TLX	Workload	6 21-point-scales
Questionnaire Premises	Acceptance of premises and lighting	visual analogue scales from 0 to 100

Tab. 5: Description and order of tasks during test phase. A whole test phase should not exceed 30 minutes. Subjective scales are marked in dark gray.

A test phase includes three subjective scales. The Karolinska-Sleepiness-Scale (KSS) is frequently used in studies investigating alerting effects of light [1]. Sleepiness is then interpreted as a measure of arousal state. The KSS exists in different versions [11]. In this study we use the 9 point Likert type scale with descriptions on every point.

The NASA-Task-Load-Index (NASA-TLX) determines the task-load that is created by performing psychomotoric tests [12]. It includes six 21-point Likert type scales, that focus on different types of workload, such as frustration or performance. These can be interpreted separately or as a collective to create a global score.

At the end of each test phase participants complete a questionnaire that includes questions about the premises. In particular, information about the acceptance of lighting can be gained.

In addition to these scales, also three psychomotoric tasks are used. All of these tasks are realized as visual computer tests with a monitor and a computer mouse. In general, these were chosen to get a more holistic knowledge about the attentional state of participants.

The first task is a six-minute psychomotor vigilance task (PVT). These kind of tasks are frequently used in studies dealing with NIF effects of light. Parameters, such as type of stimuli, duration of stimuli appearance and interstimulus interval differ significantly between studies [13–15]. However, it was intended to use parameters that fall within the range of the most commonly used realizations. In this task subjects have to press the mouse-button, whenever a yellow dot appears on the screen. Stimuli disappear after one second. The time between the occurrence of dots varies randomly between 2 and 9 seconds. Although this task is called a psychomotor vigilance task, in the style of many other studies that used such a test, in the previous described definition it can be rather considered as a task of testing sustained attention due to a higher frequency of stimuli-occurrence (see paragraph 4). Since the results of PVTs with durations of less than 10 minutes are comparable to the 10-minute version [16], a PVT duration of six minutes was chosen here in order to restrict a full test phase to less than half an hour.

The second task is a combination of a two-back and a go/nogo task. The n-back task also is widely used within this research field. It is often referred to as a working memory task, although some studies could not find strong correlations to other commonly used working memory tests. Nevertheless, it could be shown that the n-back task requires the engagement of different executive functions, which may be also correlated with working memory or predict the performance of higher cognitive functions [17, 18]. As already stated in the previous paragraph, also parameters for the n-back tasks differ between studies [19–21]. In this study a sequence of letters is presented letter by letter. If a letter equals the penultimate, a button must be pressed. Letters are presented for one second. It could be shown, that performance decreases with an increase in ‘n’. However, this increase does not seem to be linear and differences between two- and three-back seem to be more pronounced [17]. Therefore, a combination with a go/nogo task is used to further increase the difficulty of a 2-back task and also include other aspects of attention.

In general, a go/nogo task consists of target and non-target stimuli that appear in a random order. The proportion, type of stimulus and stimulus duration differs significantly between studies. Since the go/nogo part of this task is used as an additional distractor to the 2-back task, we decided to use a proportion of 50%. Target stimuli are represented by red squares, while non-target stimuli are green squares. Both appear for 1.5 seconds.

Letters and squares appear alternately on one side of the screen. The letter appears on the subject's non-dominant side, so that the mouse button for letters must always be pressed with the index finger of the dominant hand. The other mouse button must be pressed when a red square appears. This task was designed to include different types of attention. For the 2-back task, as mentioned before, working memory or at least executive functions are required. The go/nogo task includes some inhibition capacity. In particular, it is assumed that learned behavior must be suppressed when reacting to a red and not reacting to a green stimulus, since most humans associate red with 'stop' and green with 'go'.

The third psychomotoric task is a pure go/nogo task. It tests for the inhibitory potential of participants. Parameters are adapted from Wessel who found out, that an inhibitory potential in EEG data is only obtained if stimuli appear on a high pace and the proportion of go trials is high [22]. Therefore, the interstimulus interval varies between 0.7 and 1.7 seconds and go trials appear with a proportion of 80%. Stimuli are shown for 0.5 seconds. This enables the presentation of more stimuli compared to longer appearance times while not introducing irregularity due to the disappearance of the stimulus after a button is pressed. In addition, response times greater than 0.5 seconds are often defined as lapses and not taken into account when calculating means for several types of tasks [23–25]. As in Wessel's work, go stimuli are represented by yellow squares, whereas nogo stimuli are shown as cyan squares.

The combination of these psychomotoric tasks is thought to give a holistic representation of the actual state of attention of a subject, by focusing on different types of attention and executive functions with every task.

4.2 Operationalization of attention – work phase

Welcome
Test Phase 1
Office Work 1
Test Phase 2
Office Work 2
Test Phase 3
Lunch Break
Test Phase 4
Motoric Skills 1
Test Phase 5
Motoric Skills 2
Test Phase 6
Farewell

Tab. 6: Schedule of a session day. Test phases are repeated six times a day. The order of office and motoric work is randomized between participants.

As shown in Tab. *6* there are four phases of work on each session. These work phases have two objectives. As mentioned before, session days aim to simulate working days. This includes maintaining attention over several hours continuously. Since not only test phases, but also work phases require attention, they are added to the schedule. Otherwise, if subjects read, talk or relax between test phases (as often implemented in such studies) concentration does not have to be maintained over a full day [26–28]. On the other hand, also work tasks are used to get more information about the current state of attention. Since test phases are very demanding, we aimed at finding tasks, that require concentration, can be parametrized and evaluated, but are still less monotone and demanding as the psychomotoric tasks previously shown.

These considerations led to four different working tasks – two simulate office work, whereas the other require motoric abilities. A short description of the tasks and their parametrization can be seen in Tab. *7*.

	Description	Parameter
Office Work 1	Read factual texts about animals Mark words Answer Questions	(Correctly) answered questions (Correctly) marked words
Office Work 2	Factual texts about cities Typewrite Choose correct map	(Corretly) typed words Right or wrong map
Motor Skills 1	Recreate constructs ’Flexpuzzler’ (Components on elastic band)	Number of correct constructs Number of mistakes
Motor Skills 2	Draw Pattern on Template Cutting, folding Create boxes	Deviation in mm Extra kinks

Tab. 7: Description of work phases and their parameters. The order of office work and motor skills is randomized between participants.

5 Covariables

In addition to the attention on session days, we are also interested in activity and light history during the whole study block of two weeks. Activity data can be used to determine sleep duration and quality. Since it is supposed that sleep deprived subjects may be influenced by light in a different way or at least have altered arousal, it may be beneficial to test for changes in sleep [29]. Furthermore, this information can be used to investigate if participants follow a regular sleep/wake schedule The activity data is supported by an online diary, which is filled out every day. Besides activity, also light history may significantly influence a participant's alertness on session days [30]. Therefore, all participants wear two Actiwatches (Philips Respironics) during their two-week-block. These devices include accelerometers to assess activity of participants, as well as three light sensors. The light sensors have their maximal sensitivity in red, green and blue regions of the visible spectrum. The activity is measured on the wrist with one device, whereas light information is collected on the outermost layer of clothes on chest-level with the second device. The combination of sensor signals does not only allow to measure illuminance, but also gives further spectral information. This can be used to calculate an approximation of received melanopic equivalent daylight illuminance doses during session-free days.

Since also the current mood status of a participant can have an impact on the results, mood is assessed at the beginning of every test phase by a visual analogue scale.

6 Summary

In this paper, a study design that aims to investigate alerting effects of light during the day is presented. In particular, it focuses on changes in spectral composition and effects of prolonged exposure durations. All light scenes fulfill the regulations for lighting at work. This facilitates the transfer of results to real-life working settings. Additionally, fulltime work is simulated by different working phases and longer exposure duration of over seven hours. Six test phases on session days enable the investigation of light effects on attention during the day. The included tasks particularly address different cognitive processes to create a holistic representation of the attentional state of participants. In addition, light and activity devices enable an interpretation of light history and sleep parameters which can therefore be considered as covariables in detail. In summary, the aim of this study is to gain more precise knowledge on alerting effects of light at work and to help create workplace lighting that actively supports employees in the future.

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