Public Abstract – Master Thesis "Evaluation of biologically effective light in the vehicle interior in terms of subjective and objective parameters of the driver's state" by V. Westfal

What if there was a simple way to reduce accidents related to sleepiness, increase human performance, alertness, and vitality? In order to answer this question one might first think of a substance based intervention such as the consumption of caffeine or medication. However, it is much easier: The exposure to light of certain characteristics can cause these wholesome effects. Light affects the human organism more powerfully than any drug. Light sets the inner clock for the circadian rhythms in humans and many other living organisms; beside this fundamental function, light exerts multilayered effects on the human organism. Blue, bright white and blue-enriched white light are able to enhance alertness, cognitive as well as physical performance, mood, vitality, and well-being.

In the last years, research in the area of biologically effective light has flourished. With the discovery of the intrinsically photosensitive retinal ganglions cells in 2001, the breakthrough was made: the intrinsically photosensitive retinal ganglions cells are key to the understanding of how the biological effect of light is modulated. The intrinsically photosensitive retinal ganglions cells possess a peak sensitivity for light of approximately 460 nm. Light of that wavelength is perceived blueish. The intrinsically photosensitive retinal ganglions cells have neuronal connections to the superchiasmatic nucleus – which is the circadian pacemaker – and to brain areas implicated in the regulation of arousal. Further research revealed that humans possess two light sensitive pathways: the circadian system and the visual system. The intrinsically photosensitive retinal ganglions cells project to the superchiasmatic nucleus as well as to the pineal gland which essentially regulates wakefulness in relation to the lighting conditions. This mechanism is called entrainment and denotes the property of the circadian system by which the biological clock is synchronized to external time giving cues. The circadian rhythm is not synchronous in all humans; a shift of approximately two hours differentiates between morning- ("larks") and evening-types ("owls"). The circadian rhythm is associated with systematic oscillations in melatonin ("sleepiness hormone") as well as cortisol ("stress hormone") concentration, body temperature, alertness and other physiological parameters such as the activity in EEG frequency bands. Light administered after the nadir of core body temperature can advance the phase of circadian rhythms whereas light given before the temperature nadir can induce delays.

Returning to the parameters influenced by light exposure, the rich literature on that research topic was reviewed, leading to following conclusions: The effectiveness of light on subjective sleepiness was found to be independent from the time of day in laboratory as well as real-world settings, such as the workplace. Some studies (e. g. Lehrl, Gerstmeyer, Jakob, Bleich, & Kornhuber, 2007) could successfully show this phenomenon's effect within minutes after exposure. Subjects with high night-time melatonin levels who in general showed stronger subjective and performance-related impairment after sleep deprivation benefited primarily from the exposure to light.

Derivatives of attention take advantage of light exposure, albeit there are a few exemptions. On one hand, light exposure was shown to have a negative impact on selective attention in terms of accuracy; reaction times remained unaffected. The number of correct and false reactions was unaffected in a selective attention task. However, others authors (e. g. Chellappa, Steiner, Blattner, Oelhafen, & Go, 2011) were nonetheless able to show faster reaction times using the same task (psycho-motor vigilance task) under blue and bright light. On the other hand, task performance requiring a divided focus of attention profits from light exposure: Participants committed less omission errors, showed more correct responses and a higher accuracy. Reaction times however, remained the same. Additionally, reduced attentional lapses were reported.

Only a few studies (e.g. Viola, James, Schlangen, & Dijk, 2008 and Wilhelm, Weckerle, Durst, Fahr, & Röck, 2011) broached the issue of vitality and well-being but could confirm the beneficial effect of daytime light exposure on experienced vitality. This effect can be observed after long term exposure as well as after a short duration of light exposure. Many authors (e.g. Van Bommel, 2006) mention that light generally has a positive effect on well-being but do not offer further specification. Chellappa et al. (2011) found an increased well-being resulting from light exposure in the evening. Other authors (e. g. Borisuit, Linhart, Scartezzini, & Münch, 2015) report no change of physical well-being on daytime.

The results concerning performance in tasks like cognitive and visual tasks are ambiguous as both faster and unaffected reaction times are reported. Performance in complex and higher cognitive tasks tapping executive functions, working and declarative memory and visual-spatial abilities might be enhanced. In the paper based tasks, no improvement in relation to different light conditions could be found. Most studies (e. g. Kaida, Takeda, & Tsuzuki, 2012) could not prove a beneficial effect of light treatment on visual performance compared to normal lighting conditions, except from the finding of a carryover effect of daylight to nighttime performance and a relative best performance under light of 6500 K.

In daytime, laboratory and real-life settings, light enhances self-reported mood towards a more positive mood. This beneficial effect can be proven in healthy individuals and also in persons with mood disorders insofar that the intensity of depressive symptoms is reduced. High color temperatures cause lower rated depression items in terms of valence.

Although the positive effect of bright and blue light is becoming increasingly prominent, the application in daily life is still sparse. Especially safety relevant domains like air traffic, air traffic control and road traffic could benefit from the biological effectiveness of light. There is a proportionally small number of scientific publications dealing with that issue. Taillard et al. (2012) succeeded to show that sleep-deprived drivers performed better in the driving task when exposed to blue light at night compared to drivers in the placebo condition. Shekari Soleimanloo (2016) was able to show that blue-green light improved the drivers' subjective sleepiness and driving performance in comparison to the placebo condition. A study conducted by Leger, Philip, Jarriault, Metlaine & Choudat (2009) revealed that the combination of a nap and a bright light pulse reduces both objective and subjective sleepiness independent from the time of the day in professional shift work drivers. These results attained in the automotive context illustrate that exposure to light can be an adequate measure in terms of improving driver alertness and drowsiness, respectively, as well as driving performance. The use of light application is not limited to common vehicles driven by the driver: In autonomous vehicles, the occupants can be prepared for their workday, as light, besides alertness, increases also concentration, cognitive performance, sustained attention and mood.

Brown et al. (2014) applied a light therapy with blue light on flight crew and cabin crew members for a duration of two weeks. The working environment of the target group is not only coined by high safety demands but also by personal strains on the operators such as jetlag. The blue light led to a decreased self-reported sleepiness and fatigue as well as reduced physiological indications of sleepiness. However, like nearly all studies attesting the effectiveness of light, the mentioned studies were conducted under conditions which are rather far away from everyday life; participants were for instance sleep-deprived, shielded from any time giving cues or the light was applied at night. The positive effect of light can be considered proven with the limitation that the subject is in a state of diminished alertness due to experimental settings or shift work.

The studies from the automotive sector mentioned above used portable light devices or lamps installed in a driving simulator. Recently, two in-vehicle light concepts aiming to evoke a biological light effect were presented. These extend the primarily decorative function of classical ambient light towards an incremental functional character. KIA presented an in-car lighting concept called "Light-Emitted Rejuvenation system" which is designed to provide "therapeutic light" for the reduction of drowsiness, treating jetlag and improving the passengers' energy levels. Unfortunately, no information on the empirical testing of the LER system is available.

Daimler's TopFit Truck was developed based on research addressing sleep, vitalization and fitness in trucks; beside different wellness and fitness features, it possesses an ambient lighting called "Daylight+" installed to the ceiling of the driver's cabin. The lighting concept consists of red light for relaxation during breaks and blue light to keep the driver alert while driving. The reinforcement of daylight is supposed to continually adapt itself to the outside luminance conditions. It is reported that a sufficient amount of light reaches the driver's eye to successfully suppress the release of melatonin. Farkas, Leib, Betz, & Rothe (2015) were able to show for the first time that an in-vehicle, biologically effective light like the Daylight+ has a stimulating, activating and performance enhancing effect on truck drivers. The effect of blue light was compared to low levels of red light with regard to vigilance, alertness, driving skills and acceptance. The measurements were taken before and after a drive in the truck equipped with Daylight+. Due to the within-subjects design, every participant completed the subjective ratings and the objective vigilance test four times. Subjective ratings for vigilance and alertness increased after exposure to blue light compared to the placebo light. No differences in reaction times were evident but the accuracy of reactions increased as a result of the blue light treatment. Even to a more economical driving style was reported to result from the biological effective light. However, the sample consisting of eight drivers was relatively small and only little information is provided concerning the experimental setup and the frame conditions. Additionally, the intended number of control drives was not achieved. Nonetheless, the biological effect of daylight similar light was replicated. For the study at hand it also is worth noticing that the acceptance of the light device was negatively affected by unpleasant glare.

Under consideration of all insights gained from literature research, the research question whether short wavelength light by a stationary in-car light device helps to increase drivers' attention, mood and alertness as well as alertness under everyday life conditions was stated. The thesis at hand aims to answer this question. A controlled simulator study testing the impact of blue light on objective and subjective parameters of the driver's state was conducted from February to March 2017.

The study was conducted according to the Declaration of Helsinki and was approved by an Ethics authority. Dealing with a simulator study, there was no noteworthy risk; the probability of the participants becoming simulator-sick was minimal in the chosen setting. Due to the fact that the light exposure took place in the morning hours, there were no inadvertent consequences such as a delay in falling asleep to be expected.

The sample n = 23 consisted of 15 men and 8 women. Participation in the study was restricted to subjects who fulfilled following criteria: They did not travel over one or more time zones within the last two weeks, since a jetlag produces a temporary misalignment between the timing of the central circadian clock and the desired sleep times which in turn causes insomnia, daytime sleepiness etc.; due to the testings on different days, measures of participants suffering from jetlag would lack comparability. They were no shift workers, because the working schedule is not compatible with the study schedule; the early shift is currently working while exposing night shift workers to the blue light in the morning would be unethical. They were not older than 50 years, because older people tend to be early chronotypes and additionally, the absorption of short-wavelength light increases with the age due to the age related macular degeneration, while the pupil diameter decreases with increasing age. They did not participate in the pilot study, because subjects were informed about the non-visual effect of light. They did not wear of glasses and had no optical aid with color screen to assure reception of the blue wavelength light. They did not have eye diseases which could lead to a diminished absorption of blue wavelength light (dyschromatopsia was no exclusion criterion because normal trichromatic vision is not necessary for light-mediated neuroendocrine regulation). And finally, they had to own a driving license. The participants were instructed to restrain from caffeine and alcohol consumption from 11 pm on the night before the trial, as these are known to have a stimulating effect.

The study at hand was designed as a repeated measures within-subjects design with one test condition (no light vs. blue light) per day. The order of test conditions was randomized. The measurements followed on two different days. The participants were instructed to choose the time slot for the trial corresponding to their regular daily routine so that no notably shift in the wake-up time was induced. The time slots for the testing were 6:30 – 8:00 a.m. and 8:00 – 9:30 a.m. on workingdays. Since one can see it as proven that a certain level impaired alertness is necessary to achieve an observable effect of light, the only ethically conductible way was to invite participants in the morning hours. Due to its relevance in daily life and the nadir in the circadian rhythm especially of interest, the aforesaid time span was chosen.

The manipulation in the study happens through the variation of the lighting conditions via the light device implemented in the prototype vehicle. Each trial lasted 61 minutes. In the "no light" condition, there was no light except for the illumination of the cockpit instruments and the beamers used for the scenario projection administered. Participants were exposed to blue monochromatic light of 468 nm wavelength with an illuminance of 22 lx for 40 minutes after a darkness period of 20 minutes. The effect of the manipulation was measured in relation to subjective as well as objective parameters of the driver's state. These were captured at three measurement time points: Before the trial, after 20 minutes (before the blue light application), and at the end of the trial. A driving scenario comparable to the highly practiced way to work was chosen. The participants were instructed to drive maintaining a speed of approximately 90 km/h and to ignore the speed indication traffic signs in order to prevent them from dividing too much of their attention on their speed. The current speed was displayed in a simulated head-up display. Additionally, they were instructed to comply with the obligation to drive on the right. After the second testing, the participants were debriefed concerning the intention of the study and the effect of the blue light. They were asked already if they knew about the biological effect of blue light.

Multiple linear models fitted for each dependent variable revealed that neither the subjective nor the objective parameters of the driver's state were remarkably influenced by the light treatment. The absence of an observable effect may have myriads of reasons: There are indications that only a subgroup of the population is susceptible to the effect. An a priori selection of participants was not undertaken. Potential indicators for the responsiveness to the biological light effect, such as the nocturnal melatonin rise, were not measured in the study at all. It is known that factors like the time awake, sleep duration, time spent outdoors, traveling time outdoors prior to the experiment, gender, age, light sensitivity, chronotype, global sleep quality, trait vitality, general health and the subjective light sensitivity modulate the light effect. Besides practical reasons, this was not an issue of the study at hand because the utility of an alertness increasing measure should not be limited to a subgroup of users.

There are also many intra-personal factors which can distort the measurements. The testings were conducted separately on two days, one test condition each. This has the advantages that the experimental conditions did not interfere with each other and to a certain degree, intra-individual differences were supposed to be minimized. Disadvantages like variations in the sleep duration of the night before must be accepted because the with-in subjects design is inevitable for the given research question. For example, for some participants, there were considerable differences in the sleep duration the night before the trial. Some studies investigating the influence of light excluded females as participants because of the effects of menstrual cycle phase on cognitive performance during sleep deprivation and on sleep quality, due to the influence of menstrual phase and the use of oral contraceptives on, for instance, melatonin. On behalf of the ecological validity, such intra-personal variations were not profoundly considered. In general, a within-subjects design is always to be preferred over a between-subjects design since it reduces the unexplained variance.

Further, compared to other studies (e.g. Popp, 2005), the light intensity of the blue light was relatively low. A trade-off between a luminance level which could be administered safely in real road traffic and a high luminosity in favor of the biological effect had to be made. A luminance which was found to warrant appropriate view of the driver was implemented. Indeed, there is evidence that very low doses of light can alert humans. However, as already explained, such effects were observed under laboratory conditions.

Some participants reported unsolicited that they initially felt vitalized by the experimental light but that this effect subsided over the course of the trial. This hints to the hypothesis that either the light exposure, the trial or a combination of both was too long. Concerning that issue, Shekari Soleimanloo (2016) writes that „time-on-task effect or fatigue from driving is highly likely to emerge after 30 min driving […]. It remains quite possible that a longer driving time could reveal greater alerting effects of light" (p. 334).

In conclusion, the theory convincingly demonstrated that light of blue wavelength can increase alertness, mood, vitality, well-being and performance in humans. A driving simulator study was conducted to test whether is beneficial effect appears in a realistic driving scenario which was not the case for the chosen measurements. Why the vitalizing effect could not be observed is ambiguous. The identification of the true and valid determinants of the biological light effect in humans under realistic conditions could be subject of another investigation. For the everyday life application, a further refinement of the right dosage would be of greater interest. From the state of art it seems that the right formula to bringing blue light into non-autonomous vehicles on the road is yet to be.