Final project report:

Biological effects of the LUCTRA LED desk lamp (manufacturer: DURABLE · Hunke & Jochheim GmbH & Co. KG) exemplified by melatonin suppression in the evening

Test period: 1 July to 15 September 2014

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1. Project definition, goal and conditions

1.1. Project definition and goal

The task of this project implemented by Intellux GmbH was to examine the biological effectiveness of an innovative LED desk lamp developed by DURABLE Hunke & Jochheim GmbH & Co. KG (58636 Iserlohn, Germany) in a scientific study by way of experiments on test persons. The innovative LED desk lamp is marketed under the brand name of LUCTRA. This study relates in particular to the LUCTRA TABLE PRO model. Furthermore, the results were to be validated against the data contained in the corporate database. Thirdly, this report was to include a theoretical assessment of the results for other distances of the lamp from the table and other (table) surfaces.

Intellux GmbH had set itself the goal of testing the biological effectiveness of the LED desk lamp by a 30-minute exposure to its light in the evening. The primary measurement variable was the melatonin concentration in saliva before, during and after exposure to the light.

1.2 Conditions under which this project was implemented

So far, few research groups have examined the influence of different electric lighting situations systematically for biological effectiveness. However, results of such examinations are required in order to set standards and benchmarks or even to issue reliable recommendations for planning.

Our research group has been specialising in application research in the area of light & health for the last seven years and acquired several projects sponsored either by government authorities or by industry. In the PLACAR project "Plasma lamps for circadian rhythms" sponsored by the German Federal Ministry of Education and Research (BMBF) (FKZ: 13 N 8973), we defined a standardised test situation as well as an examination paradigm, which describes a comparability of different illumination scenarios relating to melatonin suppression under conditions very close to nature. The relevant database has been extended systematically since then and is the most extensive one of its kind worldwide today, with more than 30 different illumination scenarios. It seems to be a suitable basis for general characterisation of lighting systems, in addition to standards and benchmarks relating to the intensity and colour of light. The tests carried out under the commissioned project can be compared with the existing data and evaluated in this context.

The research group has won both national and international recognition for outstanding achievements in the area of light & health. The project leader, PD Dr. Kunz, is a psychiatrist and has been active in clinical sleep research and clinical chronobiology for 20 years. He has published a number of original research findings relating to melatonin, the vital hormone for the effect of light [1-6]. Evidence of his reputation in the area of light & health are: membership in DIN FNL 27 (Effect of Light on Humans); sole physician on the Scientific Committee of the German Lighting Society (TWA in LiTG), responsible for the area of melanopic effects of light; advisor to the European Commission in preparing the official report: Health Effects of Artificial Light [10].

The research group already carried out first experiments on the feasibility of melatonin suppression in the evening with various types of electric illuminations from 2006 onwards. From these experiments, important findings emerged which substantially contributed to the

preparation of the design for this study. In February 2007, the first real examination of test persons was implemented on the basis of the newly established examination paradigm. The established examination paradigm was proven viable in the subsequent test series.

The most important test method was measurement of the melatonin content in saliva to verify the suppression of melatonin under light. In Europe, this examination is basically offered by three institutes. When asked on recommendations from other European laboratories, we selected a company to carry out these measurements on our behalf. Two consecutive experiments were carried out using different methods of analysis; the results were inconsistent in both cases. From the third experiment onwards, the relevant examinations were conducted by IBL International in Hamburg, Germany. This cooperation proved satisfactory, the results were consistent and reliable.

Intellux GmbH was founded by Dr. Kunz in 2013 with the objective of carrying out research into the biological effects of light also commercially, and thus contributing to the development of intelligent, biologically optimised lighting systems.

Since the autumn of 2014, Intellux has been a part of the BMBF (German Federal Ministry of Education and Research) - sponsored joint project "OLIVE" for optimised lighting systems to improve performance and health (FKZ: 13 N 13162), which addresses jointly with other industrial partners the optimisation of various lighting systems and their biological effects on human beings

1.3. State of scientific research used as the starting point

The earth's rotation causes two of the most reliable, predictably recurring changes in nature which have an influence on human beings: the daily alternation of light and darkness and the 24-hour variation in ambient temperature. Every living organism on earth has adapted to these changes in the course of evolution, and humans have obviously done so extremely well. Light is the strongest "timer" for this synchronisation. The result is a system of inner clocks which controls and drives all daily variations within the body: organ activity, hormone production, response to medication and even genetic expression. These circadian rhythms are synchronised with each other, so that they, similar to a mathematical chaos, ensure an extremely regular process and consequently the functionality of body and mind [7].

The circadian system consists of multiple clocks. Each individual body cell contains its own 24-hour information schedule [8]. The cells must be synchronised with each other in order to do the right thing in a coordinated way at any given moment. The synchronisation of the peripheral clocks is effected via a master clock located in the nucleus suprachiasmaticus (SCN) of the hypothalamus. This master clock is synchronised with the external environment via timers every day. In this context, the timers of light and darkness are of great importance [9].

The invention of artificial light has enabled human beings to determine the time and length of day and night themselves. Experimental studies on animals and humans have shown that the extent of the biological effects of light is substantial. These findings open up a completely new perspective, since it has become obvious that, in addition to performing the visual task, artificial light has an either positive or negative influence on human performance and health [13].

On the one hand, it enables round-the-clock activities such as shift work. On the other hand, the daily alteration of the length and timing of the day causes an external desynchronisation between the external light-and-dark cycle and the circadian 24-hour rhythm. Work and training environments in the industrialised world operate primarily with artificial lighting. The standards and benchmarks for artificial lighting are oriented on visual tasks set by the various kinds of jobs, in healthcare also on comfort and wellbeing (DIN EN 12464-1 and DIN 5035).

The discovery of the retinal ganglion cells, which are intrinsically sensitive to light, the photopigment melanopsin and the description of its field of action at the beginning of this century has initiated a tempestuous new development with a flood of new basic knowledge about the non-visual biological effect of light channelled through the eyes [11,12]. The photo-pigment melanopsin on the retina transmits the information about the intensity and spectral distribution of light to nerve tracts which lead to the SCN. Melanopsin responds particularly sensitively to light within the blue spectrum, with maximum sensitivity at a wavelength of visible light of approximately 480 nm. Several research groups described fields of action which yield more accurate information about which degree of light intensity and which wave length of monochromatic light have the strongest effect on the circadian system [11,12].

First observational studies seem to confirm the basic research experiments. However, this also implies that light and darkness – each at the "wrong" time – could have negative effects. The World Health Organisation (WHO) classifies night shift work as "probably carcinogenic" and mentions the suppression of melatonin by light as a vital contributory causal factor [14]. The European Commission (Scientific Committee on emerging and newly identified health risks SCENIHR) describes potential health hazards through artificial light during the evening and night hours. Consequently, special significance must be attributed to understanding the cause-and-effect relationship and taking appropriate counter-measures.

In most cases so far, experimental studies on humans worldwide have proved the effect of monochromatic light in strictly controlled experimental settings, often with pharmacologi-cally dilated pupils. A transfer of these findings to polychromatic light, as is found in natural daylight and in interior lighting, would be highly complex and cannot yet be realised at the current state of research. For instance, the effect of light on human physiology depends on external factors (such as light intensity, photon density, duration of illumination, spectral composition, time of lighting, etc.) as well as internal factors (age, state of health, sensitivity of the retina, medication, individual phase length in response to the external rhythm of light and darkness, etc.). Polychromatic light in the evening, even of low intensity, impairs hor-mone production, cerebral activity and gene activity [15].

Light intensities similar to moonlight, and alterations in the length of days during the night over just a few weeks, induce structural and behavioural changes in diurnally active mice which are similar to those in patterns of depression [16, 17]. Internal data – hitherto unpublished – show that healthy test persons are exposed, at least in urban environments, to illumination which equals approximately one thousandth of natural daylight intensity. The question is whether light in the evening and during the night and/or darkness during the day contributes

to internal desynchronisation. If hypotheses to that effect were confirmed, this would lead to many new perspectives regarding the learning aptitude and performance of schoolchildren, and the reduction of stress and excessive strain in working life. Moreover, the retinal ganglion cells already mentioned not only receive their information via their intrinsic photosensitivity, but their responsiveness is modulated by preceding receptors, the well-known rods and cones of the visual system, depending on time, light intensity and numerous other factors.

2. Project implementation

2.1 Planning

The project was planned in cooperation with the participating assistants of PD Dr. Kunz who are either fellow staff members of Intellux (see appendix), or members of the research group "Sleep Research and Clinical Chronobiology" (Charité University Hospital Berlin), which is also headed by Dr. Kunz. The experiments were carried out from 1 July to 15 September 2014

The following steps were required for planning the study:
- Study design
- Application to the Ethics Commission of the Charité University Hospital
- Measurement and provision of the desk lamps
- Testing of the lamps and definition of the set values
- Recruitment of the test persons
- Implementation of the study
- Analysis of the results

2.2 Project schedule

The planned procedure was to test the desk lamps by means of experiments on human test persons in summer 2014, using test specimens of the lamp, and to make first evaluations available by the end of October 2014. A previously proven study design (see above) was applied. The procedure chosen will be described in detail in the next paragraphs. The implementation of the study was approved by the Ethics Commission of the Charité University Hospital prior to its commencement and all study procedures were in agreement with the Declaration of Helsinki.

2.2.1 Recruitment of the test persons

The test persons were recruited by means of flyers distributed at different universities in Berlin (FU, Humboldt Universität, TU). They were sent a number of different questionnaires and invited to come to the Clinic for Sleep- and Chronomedicine (at the St. Hedwig's Hospital) once prior to the actual study for a physical examination and an interview with a member of the study team. On this occasion, the protocol was explained once more, and the test persons gave their written informed consent to participate in the study. Sixteen test persons* (8 F, 8 M), average age: 24.2 ± 1.8 years (aged from 21 to 27) were included in the study. All test persons were healthy (initial check-up), and stated that they were not taking any medication or drugs. None of the test persons were extreme "early morning larks" or "late night owls". This was ascertained by the morningness-eveningness questionnaire published by Horne & Ostberg (HO) and the Munich Chronotype Questionnaire (MCTQ) (HO: 53.1 ± 7.3; MCTQ: 4:20 ± 54 min; average values ± standard deviations). The Pittsburgh Sleep Quality Index (PSQI), an index to exclude sleep-related health problems, which should be below 5, showed an average value of 3.2 (standard deviation ± 0.9). The average usual bedtime was 23:34 h (standard deviation: 0:46 minutes).

*the gender-neutral term "test person" is used in this report to designate both male and female

2.2.2 Study protocol for entrainment phase at home

During their first visit to the Clinic for Sleep and Chronomedicine, the test persons were also given an activity monitor (Motion Watch 8; Camntech; Cambridge; UK) and instructed to wear it continuously on their wrists for the duration of the study. The activity data recorded and the sleep diary served to monitor their normal sleep-wake cycle. For one week prior to the actual study, the test persons were required to keep regular bed- and wake times, controlled by a sleep diary and an activity watch.

Study at the Clinic for Sleep & Chronomedicine:

The study was conducted in a large room in the St. Hedwig's Hospital, where a maximum of 6 persons could be tested simultaneously. The windows were darkened so that no natural light could enter. The test places were arranged at a distance of 1 to 2 m from each other, but not screened and isolated from each other. Therefore, the test persons also wore strongly tinted glasses, in order to minimise the influence of the neighbouring test places if the exposures to light took place at different times. As the study was conducted in summer, the room temperature was kept constant below 25° Celsius by a mobile air conditioner. The test persons came to the lab on a total of five evenings (at intervals of at least four days in between study days). The study started 6 hours before their habitual bedtime. They spent the first 5 hours prior to the exposure to light and 30 minutes following the exposure to light under strongly dimmed illumination (dim light; DL; < 6 lx) and each participants sat at a single table during that time. They were not allowed to leave the table except for short toilet breaks, for which they had to wear tinted welding goggles. During the first part in DL, the test persons had to deliver a total of 11 saliva samples at regular intervals (every 10 to 60 minutes). For this purpose, they used a type of cotton wool roll (salivettes), which was kept in the mouth for a maximum of three minutes. During the exposure to light, the test persons also filled in a questionnaire to record their visual comfort. One hour before their usual bedtime, the test persons were exposed to one of a total of five different lighting conditions for half an hour (30 minutes). A test specimen of the LUCTRA desk lamp is shown in figure 1.

Throughout the entire study, at least one member of the study team was present to ensure that the protocol was followed correctly. The test persons were tested in groups of 3 to 6 individuals per evening. Between the individual tasks (but not during the exposure to light), the test persons were allowed to talk to each other or to a member of the study team. At regular intervals (but not more than 20 min before taking the next saliva sample), the test persons were served light snacks (sandwiches, yoghurts, fruit, muesli bars), and were allowed to drink water.

2.2.3 The lighting conditions

The present study was conducted with near-series test specimens of the LUCTRA TABLE PRO desk lamp.

The LUCTRA test specimens used in this study are identical with the lamps from series production in (1) the geometry of the lamp head, (2) the LEDs used and the light intensity and colour point binnings, (3) the energization, (4) the reflector used, and (5) the diffusion disc, and consequently in all parts essential for the generation and distribution of light. Photometric data measured by a neutral institution (measuring lab: DIAL Lüdenscheid, Germany) and the quality definition of the LEDs were available at the beginning of the study, they were validated by Intellux and can be perused upon request at DURABLE.

Differences between LUCTRA test specimens and the lamps from series production exist only in the structure of the housing and the manufacturing process of the lamp head, and consequently have no influence whatsoever on light yield and light quality.
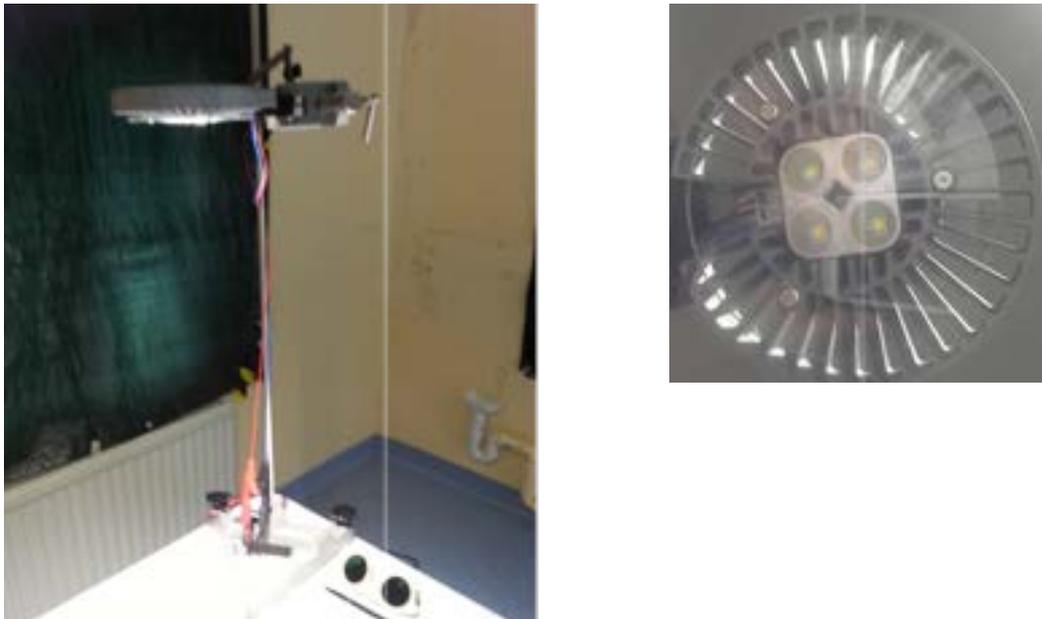
Figure 1:

Figure 1: Test specimen of the LUCTRA desk lamp (left) and the lamp head viewed from below (right). The configuration of warm white (orange) and cold white (yellow) LEDs is clearly visible.

The 5 lighting conditions comprised (see also figures 2 and 3 and table 1):

- Dim light (DL; < 6 lx): polychromatic white, weak indirect illumination (floor lamp in the middle of the room)

- Reference lighting: bright polychromatic white LED lighting (bright light; BL; indirect lighting with LED spotlight from above; approx. 1 m above the table; colour temperature: 5.500 K)

- Cold white desk lamp (LUCTRA TABLE PRO, DURABLE; colour temperature: 6.000 K)

- Warm white desk lamp (LUCTRA TABLE PRO, DURABLE; colour temperature: 2.700 K)

- Mixed warm and cold white desk lamp (LUCTRA TABLE PRO, DURABLE; colour temperature: 3.800 K)

Figure 2:

Figure 2 shows a representative example of the lighting situation with the warm white LUCTRA TABLE PRO desk lamp (on the left) and on the right the situation with the cold white LUCTRA TABLE PRO desk lamp, as tested during the study.

Figure 3:

Figure 3: shows the lighting situation for the bright light (BL) reference illumination with an LED spotlight placed above the desk.

All test persons were exposed to DL illumination on their first evening, the order of the other lighting conditions was randomized for groups of 4 to 6 persons.

Photometric measurements were carried out on the lamps prior to the study (see table of settings for the individual test places in appendix 2). The maximum possible energization of the warm white LUCTRA test lamp yielded an average light intensity of 115 lux. Therefore, the two other lighting situations were also set at this light intensity in order to obtain a comparison of the biological effects, with differences based solely on the lamps' colour temperatures and not on varying light intensities. It must be added that higher light intensities are certainly possible for the mixed and especially the cold white lighting situation.

Special care was taken to keep the lamp head invariably 70 cm above the surface of the table and directed vertically towards the centre of the table (Figure 1). During their half-hour exposure to light, the test persons were instructed to look straight at the centre of the table (Figure 4). The test persons carried out various visual tasks, including completion of a questionnaire to give their subjective assessment of the lighting situation in each case. Half an hour after the end of their exposure to light, the test persons were allowed to go home.

Figure 4 shows a representative example of a lighting situation for a seated test person. The lamp head was fixed at a height of 70 cm, the lamp pointed towards the centre of the table (50 x 50 cm), and it stood at a distance of 50 cm from the wall. The table was covered with a white cloth. A table surface with minimal reflection of the light was chosen, which simultaneously absorbed as little light as possible.

The test persons sat at the table with both forearms resting on the table and were instructed to look at the centre of the table as long as they had no visual tasks to perform (on paper). Whenever the illumination had to be switched on earlier than at a neighbouring place (in accordance with each person's usual bedtime), the test persons still sitting in DL were asked to wear strongly tinted welding goggles during that time.
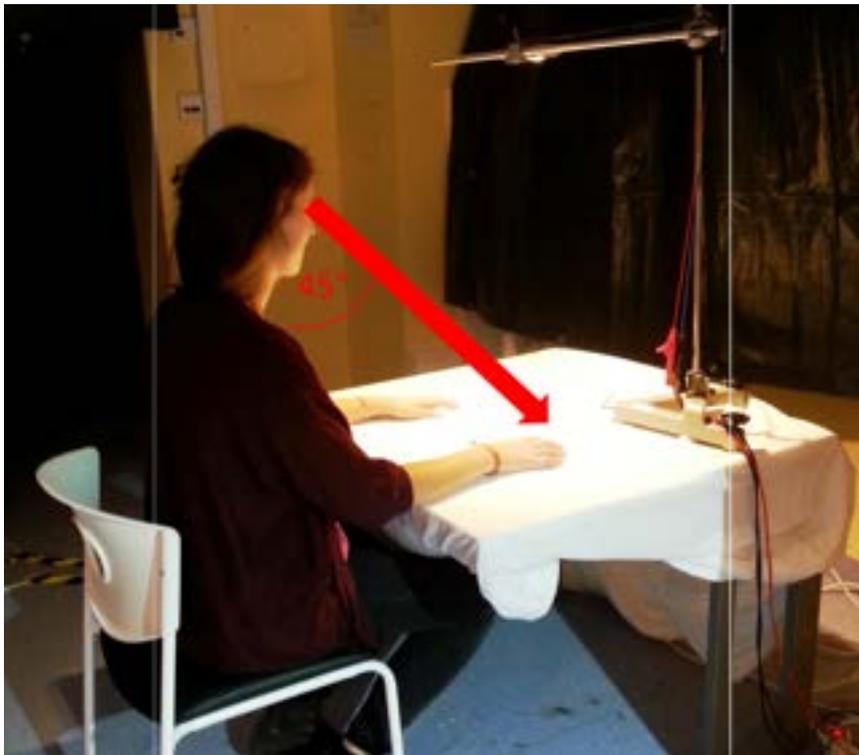
Figure 4

Figure 4: Representative example of a test person sitting at the table under the warm white DURABLE desk lamp (situation is shown with a member of the study team). The red arrow indicates the desired viewing direction. This was closely monitored during the exposure to light.

3. Results

3.1 The lighting conditions

The settings for the three LUCTRA test specimens were chosen to ensure that all three lamp heads showed the same photopic values. These were on average 115 lux on a vertical plane at the eye level of a test person facing the table at a 45° angle (see figure 4). To set and verify these values, the spectroradiometer head was fastened to a wooden rod at a 45° angle, and the values were checked prior to every session of the study.

Figure 5a shows an example of the spectral power distribution of the three LED lamp heads, and figure 5b shows the spectral power distribution of all tested illuminations including the bright LED reference lamp (= bright light; BL) but excluding DL. Figure 5c shows the weighted light intensity values for each of the individual photo pigments for the cold white and for the warm white illumination (see also table 1). Figure 5c shows the weighted light intensities of the individual photo pigments (see also table 1).
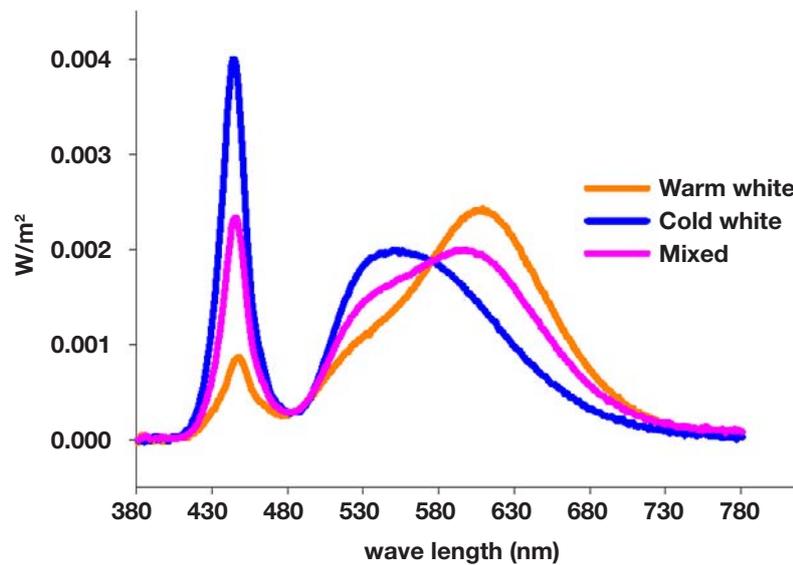

Figure 5a
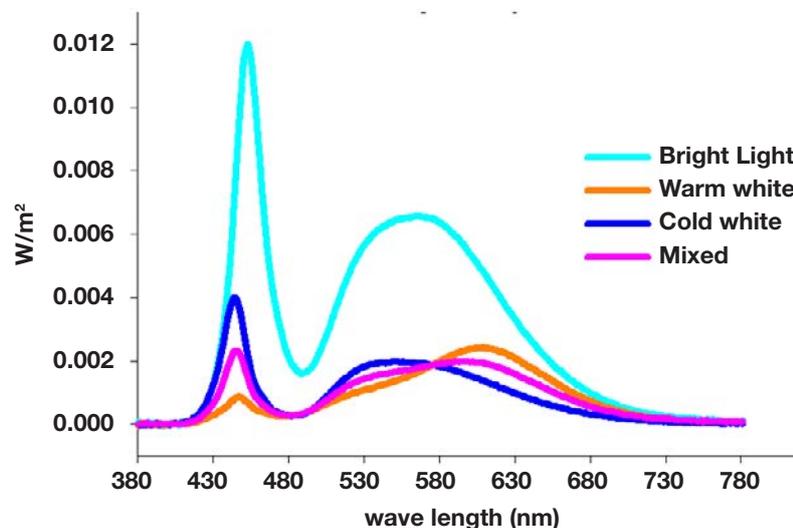*Measurement at eye level (in the direction of the table top, 45°)*

Figure 5b

Figure 5a and b: The two illustrations show the spectral distribution in W/m^2 for the 4 out of 5 illumination scenarios within the range from 380 to 780 nm.
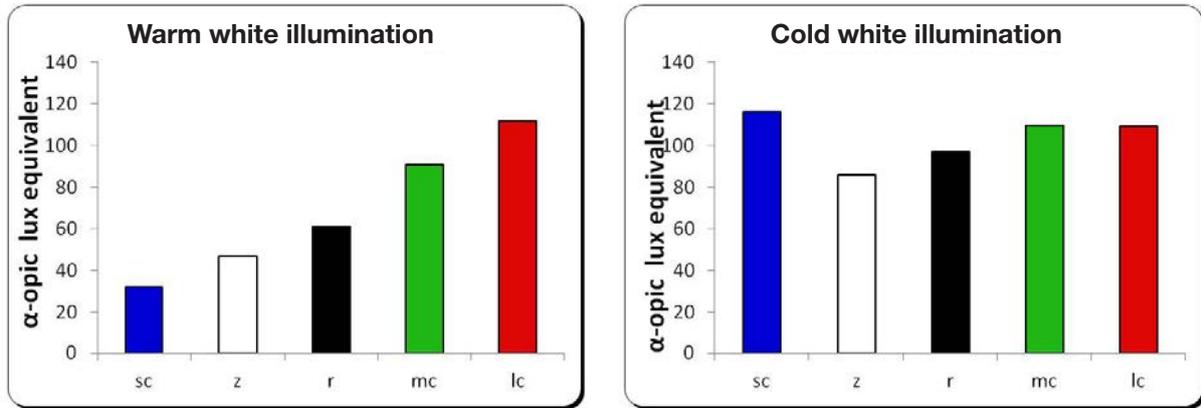
Figure 5c

Figure 5c shows the bar diagrams of the weighted light intensity for the warm white and cold white illumination situations of the LUCTRA test lamps. Sc= S cones; z= melanopsin; r= rods; mc= M cones; lc= L cones. (Source: Irradiance Tool; Lucas et al. 2014 [20]).

Table 1

			Warm white	Cold white	Mixed	Bright Light
Name	Sensitivity	I_{max}	α-opic lux	α-opic lux	α-opic lux	α-opic lux
Cyanopic	S cones	419.0	31.98	116.04	71.01	364.58
Melanopic	Melanopsin	480.0	46.81	85.67	65.87	319.40
Rhodopic	Rods	496.3	61.08	97.07	78.69	343.69
Chloropic	M cones	530.8	90.98	109.38	100.13	375.10
Erythropic	L cones	558.4	111.60	109.07	110.92	370.68
Photopic lux	–	–	113.00	115.70	114.70	389.10

Table 1: Shows the weighted (= effective) lighting intensity (in α-opic lux; see [20]) for the different photo pigments in the 3 different illumination situations of the LUCTRA test lamps and the BL situation.

3.2 Melatonin concentration in saliva

The samples were taken at the planned intervals, i.e. once every hour until 10 minutes before the exposure to light, then every 10 minutes until shortly before the end of the session (total of 11 saliva samples). Under DL the saliva collection schedule was altered slightly. To enable a comparison with the other lighting conditions, the concentrations of the DL situations were calculated by linear interpolation for the other points in time. The individual samples taken were placed in the refrigerator and frozen to -20° C at the end of each session. At the end of the study, all samples were sent in deep frozen condition to an external laboratory (IBL in Hamburg). For the direct radio-immuno assay (RIA), a proprietary antibody of the lab (a poly-clonal rabbit antibody) with a sensitivity limit of 0.3 pg/ml was used. The variation coefficients as a measure of measurement accuracy were calculated from controls which the laboratory had delivered with the samples. The intra-assay coefficient was between 8.2 and 12.5% for low and between 7.0 and 10.4% for high concentrations. The inter-assay coefficient was 10.9% for low and 9.0% for high concentrations.

In seven measurements, there was not sufficient saliva on the salivette; one data point was linearly interpolated because it was twice as high as the previous and subsequent values. The melatonin concentrations were shown as absolute average values (pg/ml) for all test persons and for every lighting condition. To calculate the melatonin suppression, all values during (and after) the exposure to light were shown as a quotient of the melatonin concentration immediately before exposure to light. In five profiles, the increase did not take place at all or not prior to the exposure to light. These particular sessions (of two test persons) were not included in the analysis. Figure 6 shows an example of melatonin profiles from one test person across all five different lighting conditions. These profiles show that the absolute melatonin concentrations in this test person began to rise in dim light, i.e. prior to exposure to light (about four hours before the usual bedtime). This is a normal raise of hormonal secretion in the evening to be expected in a test person with a regular sleep-wake cycle (i.e. this test person is entrained). The melatonin concentration was suppressed to a varying degree by the 30-minute exposures to the different lighting conditions.
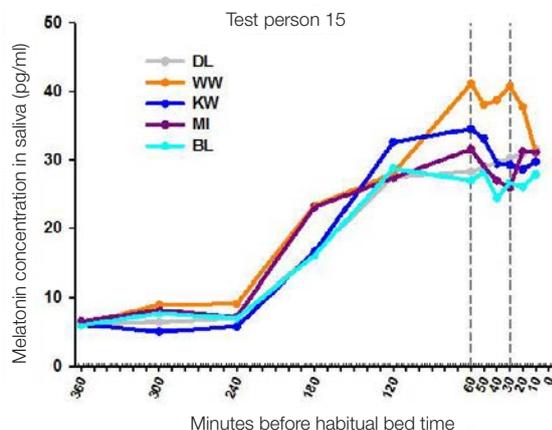
Figure 6:

Figure 6: Representative example of the melatonin concentrations in the saliva (pg/ml) in the course of the 5 study sessions of one particular test person (#15). DL = dim light; WW = warm white; KW = cold white; MI = mixed; BL = bright light.

The differences in melatonin suppression between the various lighting conditions were normalized (z-transformed) and calculated according to the mixed linear regression model using the SAS statistics software (version 9.3; Statsoft), and the p-values of the post-hoc calculations were adjusted for repeated measurements (Tukey-Kramer test). The lighting condition was defined as a fixed effect (main effect of the lighting conditions 1-5). The points in time during exposure to light were averaged, and the factor "test person" was taken into account as a random effect within the model. The degrees of freedom were adjusted according to the Kenward-Rogers method.

In figure 7, the absolute melatonin concentrations are shown relative to habitual bedtime. From visual inspection one can see that a clear increase of melatonin concentrations in DL (i.e. before light exposure) took place under all lighting conditions, and that the subsequent exposure to light led to varying degrees of melatonin suppression.

Figure 7:

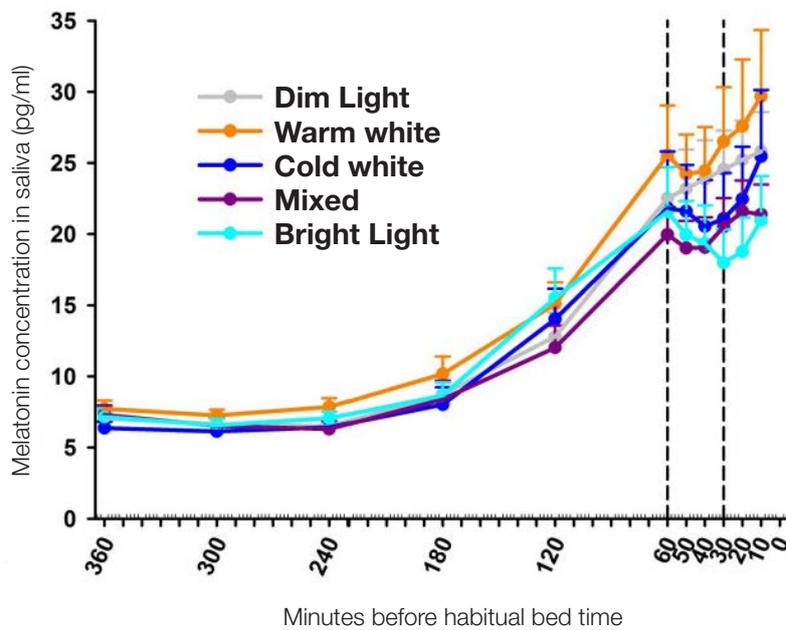*Figure 7: The melatonin concentrations in saliva are shown as averaged values per lighting condition. The following colours represent the 5 lighting conditions: dim light (DL; grey symbols); warm white (orange symbols); cold white (blue symbols); mixed (dark red symbols); bright light (BL; turquoise symbols). N= 16 plus standard error. The two dashed vertical lines show the interval of the experimental exposure to light.*

In order to compare the degree of melatonin suppression under the various lighting conditions regardless of the absolute initial concentration before exposure to light (which showed no significant differences; p = 0.1), the averaged values during the exposure to light were normalized (z-transformed), and the analysis performed as described before (Figure 8). There was a significant main effect for the factor 'lighting condition' factor (F470 = 5.78; p = 0.0004). The statistical post-hoc tests revealed that the mixed and BL conditions showed a significant melatonin suppression effect compared to the DL and warm white illumination (p < 0.05; Table 2a). A definite trend emerged for the differences between the warm white and cold white illuminations (p = 0.08; Table 2a). When the DL control illumination was left out in the regression model, a significant melatonin suppression was found in all three lighting conditions with higher blue-light containing portions of light when compared to the warm white illumination (p < 0.009; Table 2b).
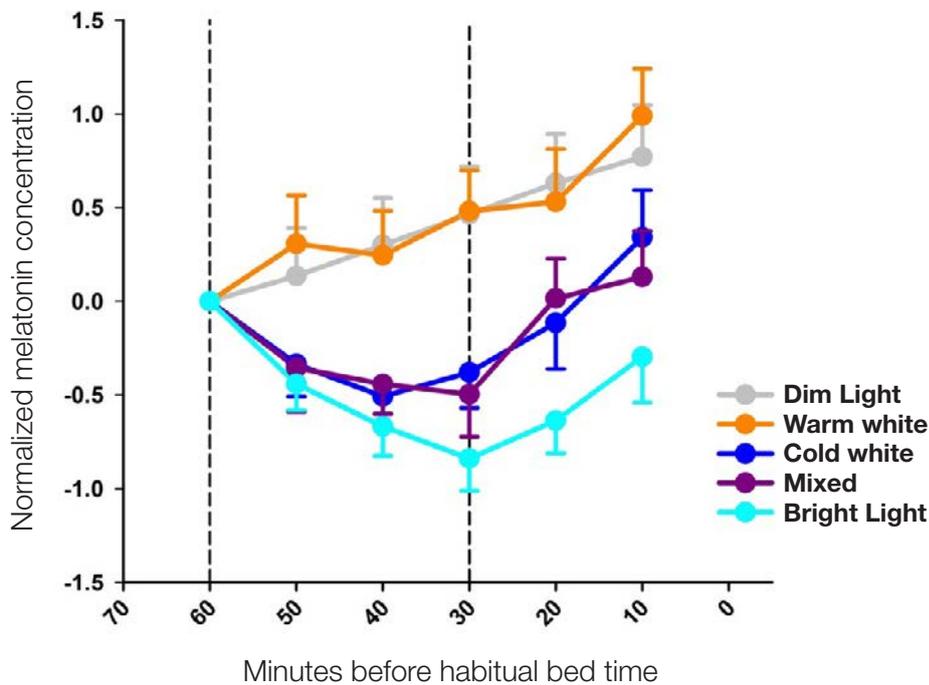
Figure 8

Figure 8: The average values per lighting condition of the normalized melatonin concentration from commencement of exposure to light (= 0). The individual lighting conditions were: dim light (DL; grey symbols); warm white (orange symbols); cold white (blue symbols); mixed (dark red symbols), bright light (BL; turquoise symbols). N = 16 plus or minus standard error. The dashed vertical lines show the interval of the experimental exposure to light.

Table: 2a

Differences in average smallest squares values

Effect of	Condition	Condition	Estimated value	Standard error	DF	t-value	Adj p
Illumination	Dim Light	Warm white	-0.05378	0.2861	70	-0.19	0.9997
Illumination	Dim Light	Cold white	0.7139	0.2913	70	2.45	0.1141
Illumination	**Dim Light**	**Mixed**	**0.8174**	**0.2913**	**70**	**2.81**	**0.0492**
Illumination	**Dim Light**	**Bright Light**	**1.0006**	**0.2814**	**70**	**3.56**	**0.0059**
Illumination	Warm white	Cold white	0.7677	0.2958	70	2.6	0.0822
Illumination	**Warm white**	**Mixed**	**0.8712**	**0.2958**	**70**	**2.95**	**0.0344**
Illumination	**Warm white**	**Bright Light**	**1.0544**	**0.2861**	**70**	**3.69**	**0.004**
Illumination	Cold white	Mixed	0.1035	0.3008	70	0.34	0.9969
Illumination	Cold white	Bright Light	0.2867	0.2913	70	0.98	0.8615
Illumination	Mixed	Bright Light	0.1832	0.2913	70	0.63	0.9699

Table: 2b

Differences in average smallest squares values

Effect of	Condition	Condition	Estimated value	Standard error	DF	t-value	Adj p
Illumination	**Warm white**	**Cold white**	**0.9034**	**0.2735**	**55**	**3.3**	**0.0089**
Illumination	**Warm white**	**Mixed**	**1.0516**	**0.2735**	**55**	**3.85**	**0.0017**
Illumination	**Warm white**	**Bright Light**	**1.2021**	**0.2645**	**55**	**4.55**	**0.0002**
Illumination	Cold white	Mixed	0.1482	0.2781	55	0.53	0.9507
Illumination	Cold white	Bright Light	0.2987	0.2693	55	1.11	0.6855
Illumination	Mixed	Bright Light	0.1505	0.2693	55	0.56	0.9438

Table 2a–b: These two tables show the post-hoc tests of the mixed linear regression. The most significant differences are shown in bold print (n = 16). SF = standard error; DF = degrees of freedom, adj. p = adjusted p-value.

3.3 Visual comfort

In the middle of the 30-minute exposure to light, the test persons were requested to rate their subjective assessment of the illumination for each lighting situation. For visual comfort, the German translation of the Office Lighting Survey (OLS; [19]) was used. This instrument contains a total of 16 questions addressing the subjective assessment of electric lighting in office rooms. Here, we report the results of a total of 6 items. The assessment could be given by placing ticks, such as: ..."I like the light in this office"... Answer: yes (1), rather yes (2), rather no (3), no (4). The not normally distributed results were compared per item and lighting condition with the other lighting conditions by means of a Wilcoxon matched pair test. In the visualisation, the averaged values were shown, where necessary, per item as:

y = 1 minus value, in order to show invariably the same direction for positive effects. For the results presented here (items 1, 3, 4, 11, 15, 16), the following assessments had to be made:

- I like the light in this office (Figure 9)

- The light in this office seems too bright to me (Figure 10 a)

- The light in this office seems too dark to me (Figure 10 b)

- If I compare the lighting situation here with an office where I worked before, then I would say that the light situation here is ... (Figure 11)

- In the course of a working day, I could imagine working in this lighting situation for ...hours. (Figure 12)

- The colour of my skin looks unnatural in this light (Figure 13)

The test persons generally liked the DL illumination least and preferred the warm white and mixed illuminations to the cold white and BL conditions (p < 0.05; Figure 9). No significant difference emerged between the warm white and mixed illuminations (p = 0.17).

Figure 9
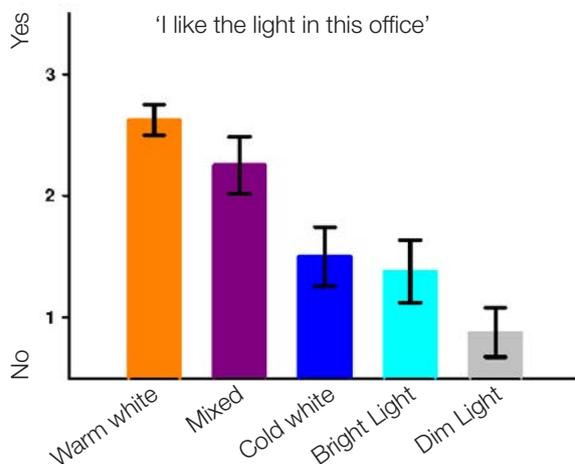
The test persons found the DL condition too dark, but the warm white illumination neither too bright nor too dark. The cold white and BL conditions were classified as significantly too bright (compared to the warm white illumination). The mixed illumination was classified as brighter than the warm white, but less bright than the BL condition ($p < 0.05$; Figures 10a–b).
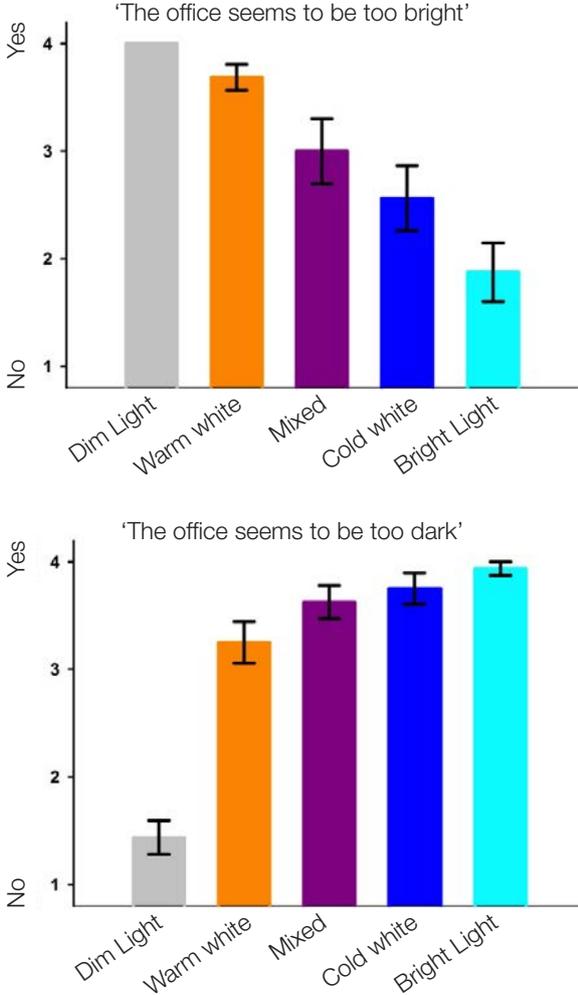
Figure 10a–b:

'The office seems to be too bright'

'The office seems to be too dark'

Figure 11:

If I compare the lighting situation here with an office where I worked before, then I would say that the light situation here is …'

Figure 12:

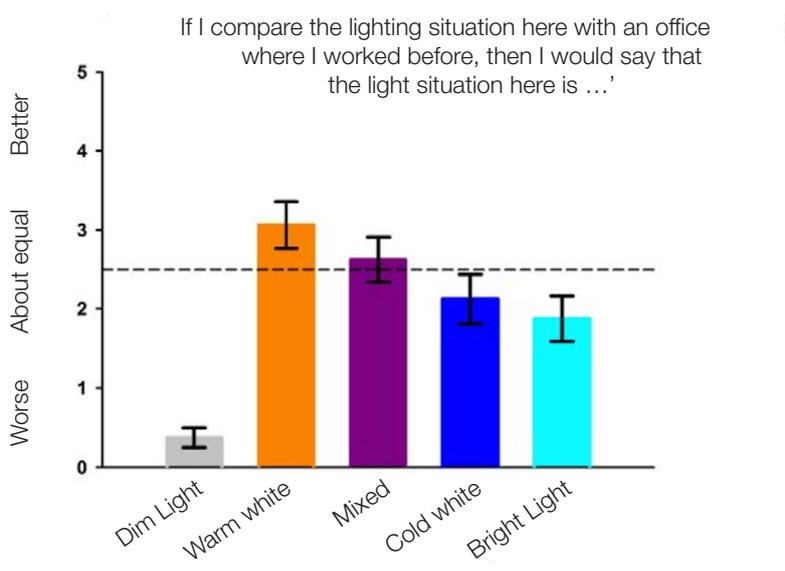'In the course of a working day, I could imagine myself working in this lighting situation for ... hours'
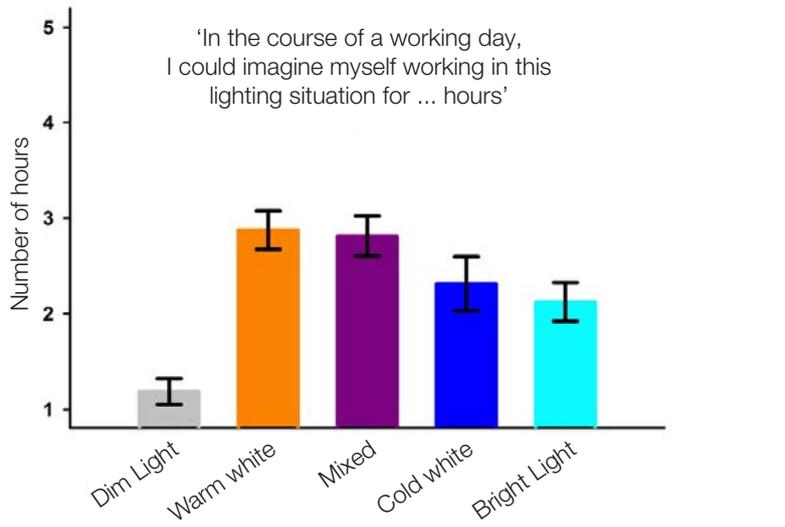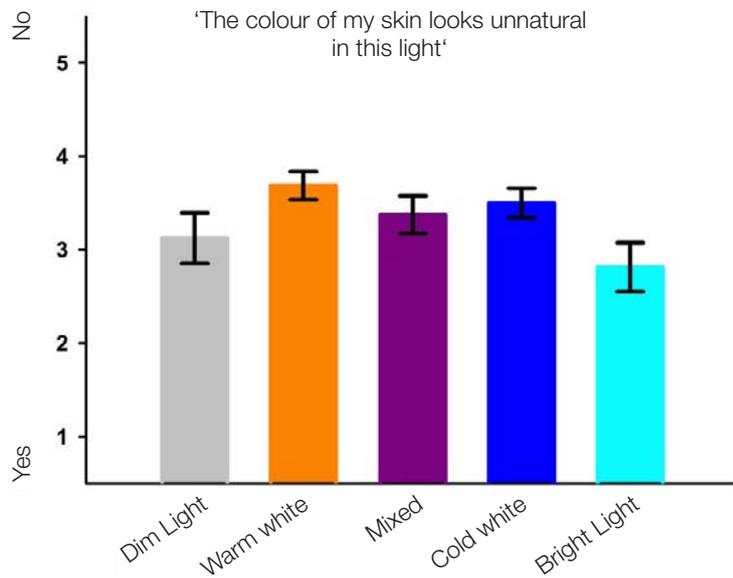
Figure 13:

Figure 9–13: Average values of each item in the colour of the subjective assessment of each lighting condition: DL (grey); warm white (orange); mixed (dark red); cold white (blue); BL (turquoise). N = 16; ± standard error.

The test persons stated that, compared to an office they normally used, they found all lighting conditions better than DL, and the warm white and mixed illumination situations better than BL ($p < 0.05$; Figure 11). In the course of a normal working day, all test persons could imagine themselves working for significantly less long in DL than in all other illumination situations, but also significantly longer under warm white light than under BL (Figure 12). The test persons could also imagine themselves working significantly longer under mixed light than under cold white light or BL. The colour of the skin appeared to the test persons more unnatural under BL than under warm white light (Figure 13).

4. Summary of results and verification of goal

The results of this project showed that the three LUCTRA test specimens of the LUCTRA LED desk lamp provided by DURABLE had varying biological effects on melatonin suppression in the evening. Significant melatonin suppression was measured for the mixed LED illumination, and with the omission of the DL condition also for the cold white LED illumination, compared to the warm white illumination. The subjective assessments of the desk lamp showed that in this illumination situation during the evening preference was given in most cases to the warm white and to some extent also to the mixed LED illumination over the two reference illuminations (DL, BL) and also over the cold white LED illumination.

To sum up, it can be said that the goals of the implemented project have been reached. Future analyses, some still outstanding, will be taken into account in future projects together with the findings from this project, with the aim of creating optimal, individually tailored lighting for different times of day and seasons of the year, taking personal characteristics into account as well, such as the gender and chronotype of each individual

Cold white and mixed light in the evening

By way of comparison with results contained in our database, we can say that the melatonin suppression results of the mixed and cold white LEDs are comparable with those of a recent study, in which a brighter blue-enriched polychromatic illumination from a ceiling lamp (about 500 lux) was used. This illumination also suppressed the increase of salivary melatonin concentration in the evening and is comparable to our results. Although a relatively low light intensity was chosen for the LUCTRA test specimens, we were able to measure significant melatonin suppression by the mixed light, and with a trend also for the cold white illumination, compared to dim light. It can be assumed that these effects could be even stronger when using a different table surface, for example one with a higher reflection rate.

Certainly an interesting result is the fact that the mixed light, which had also shown a significant melatonin suppression compared to the warm white illumination, was assessed as about equally pleasant by comparison to the latter.

Warm white lighting during the evening

The results for the warm white lighting, which showed no significant melatonin suppression compared to DL, are also comparable to results from our database. The comparison was made with lamps in which, in contrast to the test specimens of the LUCTRA LED desk lamp, the proportion of blue had been totally suppressed. The test persons clearly preferred warm white. At the same time, the warm white illumination was experienced as significantly more pleasant compared to cold white light in the assessment of visual comfort. There was no difference in the impairment of visual abilities between the three LUCTRA test lamps. Here, it can be stated that the clear preferences of the test persons concerning colour temperature are comparable with the results of other studies, although gender differences should also be taken into account. From a chronobiological point of view, these preferences seem not very surprising, since under normal circumstances in the evening (and considered from the perspective of evolutionary biology) a warm white illumination is more "physiological" than a bright cold white light, which suppresses melatonin.

The table surfaces

Concerning surfaces, no conclusive statements can be made, since the surface used in this study certainly constitutes a special case (i.e. avoidance of reflection in the interest of isolated consideration of the effects of the light). Other surfaces would certainly have to be tested separately. Moreover, office work is generally performed with a laptop or permanently installed computer. This situation also requires specific adjustments of lighting, which could not be tested in the context of this study.

Considerations concerning the use of the various lamps

In this project, the biological effects of the three desk lamps from DURABLE were tested for 30 minutes in the evening. It was shown that the warm white LED illumination met with a very high rate of acceptance by the users. This lamp could certainly be recommended for rather relaxing tasks during the evening, without the melatonin concentration increase being disrupted, and so falling asleep should present no problems. Another possibility is the dynamic setting of the lamps. It is conceivable that a brighter desk lamp with a higher colour temperature would have an activating effect during the day. Towards evening, both the colour and the intensity of light could then be reduced.

DURABLE is currently working on a lamp of this type, which could lead to some interesting aspects regarding such a dynamic use with biological effects in view.

Limitation of general statements

Whether the tested desk lamps should also be recommended as the sole source of electric lighting during the day (especially in the absence of daylight), must be regarded as doubtful at least with the light intensity chosen for this project. Moreover, a cold white or mixed illumination used in the evening before bedtime could have a negative effect on the quality of sleep.

Berlin, 23 February 2015

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6. Appendix

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Appendix 2:

The power connection settings of the lamps in 4 or 5 different places

Warm white and cold white separately

Place 1		Place 2		Place 3		Place 4		Place 5	
KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)
0.67	0.85	0.65	0.81	0.66	0.91	0.7	0.9	0.73	0.89

Both channels active

Place 1		Place 2		Place 3		Place 4	
KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)	KW (Channel A)	WW (Channel B)
0.27	0.4	0.32	0.41	0.28	0.39	0.35	0.39