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Bioadaptive Lighting

How a bioadaptive lighting solution in the working environment
improves employees' wellbeing

Zumtobel Research

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1. Summary

Employees tend to spend many hours in the office and have limited access to daylight. Thus, artificial lighting in the working environment does not only play an important role facilitating human vision, it is the main source of information for the organism's circadian synchronization and it influences the emotional and cognitive state of employees.

The results of a study carried out by Zumtobel, in collaboration with the Fraunhofer Institute for Industrial Engineering IAO, helped to determine the main factors that influence the subjective perception of light quality in office environments. Based on the results, Zumtobel developed an optimal lighting solution to satisfy the needs of office workers. However, the psychophysiological effect of the new bioadaptive lighting solution was still unknown.

Aiming to understand the implicit benefits of bioadaptive lighting, the present study was carried out in real working conditions and used a combination of different neuroscientific methods. This allowed the measurement of emotional and cognitive responses to a new human-centric lighting system specially designed to support the biorhythm of employees in their office environment.

The results showed that the new bioadaptive lighting system had a soothing and balancing effect on the participants. It significantly improved their wellbeing, reduced their arousal levels and improved their organism's capacity to cope with stress during the execution of their normal tasks, as well as during the performance of a cognitive test.

Although the participants' performance on an attentional task was not significantly improved, the participants were more focused on the task under the influence of the new lighting solution.

In summary, the obtained insights confirm the emotional and physiological benefits of a human-centric lighting solution and emphasize the importance of lighting systems that satisfy the bioadaptive needs of the employees.

2. Background

Light does not only enable visual perception; it also promotes emotional wellbeing and plays a key role in the regulation of physiological processes. Properties such as brightness and temperature of natural light serve as a reference to the organism for the secretion of cortisol, serotonin and melatonin. These hormones are involved in the regulation of our sleep-wake cycle, a 24-hour daily pattern consisting of approximately 8 hours of sleep and 16 hours of wakefulness. The healthy functioning of this cycle is essential to prevent physical and psychological health issues like fatigue and depression.

Since most of our daily routine activities are performed indoors, for instance while working, our exposure to natural light is limited. Regardless of the season, artificial lighting is almost permanently switched on in most of the offices (Zumtobel Lighting GmbH / Fraunhofer IAO, 2014) and serves as the main source of light for employees. Thus, it has the same biological-regulating function as natural light.

In a common office environment, the planning and implementation of lighting systems rarely take the needs of the workers into consideration and base on existing standards and regulations. Being aware of this issue, Zumtobel, in collaboration with the Fraunhofer Institute, conducted a study called “Lighting quality as perceived in offices”. This study not only revealed a substantial discrepancy between the existing lighting conditions in office environments and the users’ preferences, but also helped to develop an optimal office lighting solution.

The most significant results of the abovementioned study referred to the light distribution, the individual adjustability of the lighting systems, the illuminance level and light’s colour temperature. For instance, 82% of the participants indicated their preference of a lighting solution with a combination of direct and indirect components. Those who were in contact with this type of lighting reported a higher wellbeing level. Furthermore, the majority evaluated a colour temperature in the range between 4000 and 5000 Kelvin as their favorite and preferred an illuminance level of 800 lux or higher. Finally, the subjectively perceived wellbeing was also improved when the participants were able to individually adjust the lighting according to their needs and to variable work settings.

Applying the knowledge gained from the research, Zumtobel developed a new lighting system that satisfies all these needs and supports the healthy functioning of the biorhythm by simulating the course of natural light. It was hypothesized that with these new features, the benefits of this bioadaptive lighting system would go beyond the perceptual level and have a positive impact on the wellbeing and health of employees, which in turn, would improve their working capacity.

This study was carried out in autumn 2016 in collaboration with Gruppe Nymphenburg Consult AG and tested the emotional and cognitive effect of the new developed lighting concept. The neuroscientific tool Limbic® Emotional Assessment (LEA) was used to measure the impact of the bioadaptive lighting solution compared against a common office lighting system on six different psychophysiological indicators. The results helped to confirm the hypothesis that the new lighting solution fulfills the psychophysiological needs of employees and thus improves their wellbeing.

3. Methods

a. Measurement tools

Limbic® Emotional Assessment is a tool that combines different methods commonly applied in neuroscience and psychophysiology to measure the bodily processes that accompany emotional responses to a determined stimulus or situation.

For example, imagine you are waiting for a blind date at a restaurant. As you see your date approaching, your heart starts rising and your hands start to get sweaty. Nevertheless, those are not the only bodily responses taking place at that moment; there are many other physiological and cognitive responses that can be measured and that are not consciously perceived or manipulated. These responses, however, provide information about the level of activation and awareness, about the positive or negative emotionality evoked by the situation, and about the behavioral reaction to that specific situation.

Understanding the emotional and cognitive state is not only relevant in highly emotional circumstances such as the one described above, it is also very important when trying to find the factors that influence our wellbeing and health. Therefore, highly sensitive and precise methods like the ones used by LEA, are the key to analyze even the smallest changes coming from physiological responses to determined emotional and cognitive states (e.g. brain waves, skin conductance, cardiovascular indicators, among others).

For this study, LEA provided insights about the emotional and cognitive state induced by two different office lighting scenarios. By applying LEA, valuable information about the biological effect of a dynamic lighting solution was gathered from office staff under real working conditions.

Furthermore, the sustained attention task of the "Test of Attentional Performance (TAP; Zimmerman & Fimm, 2002)" was applied as a psychometrical assessment tool for the cognitive performance of the participant employees. This task requires a continuous maintenance of vigilance over a period of 15 minutes and measures the response accuracy and speed of the subjects. A second function of this test was to elicit a stressful situation and observe the physiological responses of the participants after their exposure to each one of the two lighting scenarios.

Finally, the "Trier Inventory for Chronic Stress" was applied as a self-report measurement of the employees' subjective stress perception. The gathered information served as a control variable for the sample's homogeneity, as well as a comparison variable between lighting conditions regarding the subjective stress level.

b. Test scenarios

Two common offices of similar size, within a normal office environment were used as test scenarios. The location of the furniture was the same in both cubicles, as well as the amount of natural light coming from the windows. Both offices where equipped with LED lighting with a broad light beam and homogeneous light distribution. However, the intensity and the temperature of the light differed in both rooms. Whereas the lighting system of the control room (common office lighting) had a constant temperature of 4000 Kelvin and a brightness of 500 lux, the temperature of the human-centric lighting in the test room varied dynamically between 3000 and 6000 Kelvin and had a higher intensity of 800 lux.

c. Participants

The sample consisted of 23 persons from ten different nationalities. Twelve of them were female and eleven male, all of them between the ages of 25 and 55 years. The participants were Zumtobel's office employees from different departments and different positions.

All participants were internally recruited and were asked to keep both testing days free from external meetings, so they could stay inside of the testing rooms during the examination. The employees brought their personal computers and items to the testing rooms on those days to make sure they could work under normal conditions.

d. Procedure

The bodily reactions of each person were measured during two complete workdays. To compare the effect of the common lighting system with the effect of the new bioadaptive lighting solution, the participants spent one complete workday in the control room and one in the test room while their physiological responses were measured.

The measurement took place the same day of the week for two consecutive weeks. There were two persons in one room on the same day and the assignation of the room was carried out in a random way.

The measurement procedure was the same on both days: After being welcomed by the investigator, the participants received a brief explanation about the study and were instructed to stay in the assigned room during the complete workday.

Afterwards, a saliva sample was taken as an indicator of the morning cortisol level, and the electrocardiogram electrodes were placed on the subjects' chest. The heart rate was measured for a period of 4 hours while the employees completed their normal tasks. During this period, short breaks were allowed, just as on a normal workday. The measurement was carried out the whole time using a portable recording device.

After the first 4 hours, a second saliva sample was taken and the employees had a short lunch break. Once they were back from the break, one by one, the participants entered a different, isolated room where the examiner explained the second part of the measurement to them. For this part, additional electrodes were placed on the participants' heads, fingers, on the palm of their hands, and on their face to measure further psychophysiological parameters.

The placement of the electrodes was followed by a one-minute baseline measurement of the participants' physiological activation state at rest, which allowed comparing the activation level between subjects and the proper calculation of physiological activation.

Subsequently, the participants performed the sustained attention task of the "Test of Attentional Performance (TAP; Zimmerman & Fimm, 2002)" with a duration of 15 minutes in front of a personal computer with a screen size of 15 inches. Their physiological responses were recorded during the completion of the task.

At the end, the examiner removed the electrodes and asked the participants to answer the self-report tool aimed to gather information about the subjective stress level. The second part of the measurement had a total duration of about one hour.

4. Data analysis

The first step of the analysis was the control of measurement artifacts (data noise). Simplified, this is done by using filters, which will discard abnormal or noise data and leave only the meaningful data for the main analysis. This procedure was performed for each of the testing periods, i.e. for the baseline measurement, the long-term measurement and the attentional measurement.

In order to obtain the mean values of each psychophysiological indicator (e.g. heart rate, skin conductance response, among others), the individual base line data was subtracted from the activation data.

The main data analysis consisted of the comparison of the mean values of each indicator across subjects and conditions. For this step, an Analysis of Variance with repeated measures was performed. In this case, there were two conditions, the test room and the control room.

5. Results

The study was conducted in order to test the emotional and cognitive effect of a new human-centric lighting solution in comparison to a common office lighting under normal working conditions. It was hypothesized that the bioadaptive lighting would improve both the emotional state and the cognitive performance of the participant employees.

The measurement was divided into two parts. In the first long-term part, participants executed their normal working tasks while their heart rate was measured using a portable electrocardiogram device. For the second part, further psychophysiological parameters were recorded to obtain additional information about the cognitive and emotional responses to a stress situation elicited by an attentional performance test. Since the same procedure was carried out during and after the stay in the control room (common office lighting) and in the test room (bioadaptive lighting), a comparison between the effect of both lighting solutions on the emotional and the cognitive state of the participants was performed.

The measurement of the psychophysiological data was carried using the neuroscientific tool, Limbic® Emotional Assessment. This tool allowed the objective analysis of the emotional and cognitive responses of the participants to the lighting scenarios.

a. Long-term measurement

The heart rate data provides important information about the mental load and level of tension or relaxation when the average beats per minute are analyzed. Additionally, an analysis of the change in the time intervals between adjacent heartbeats (i.e. the heart rate variability) delivers meaningful information about the psychological resilience, i.e. the capacity of the participants to cope with stress. Relaxation and psychological resilience are characterized by a lower mean heart rate and a higher heart rate variability.

Although participants solved their regular tasks on both days, they were 3.2%[1] less tense during their exposure to the new light. In addition, the participants were on average 15.2%[2] more capable to cope with stress under these new lighting conditions as compared to the room with static luminaries. In general, the test room evoked a statistically significant better mental state (see Figure 1 and 2).

1) Tension level based on the measured mean heart rate.
2) Capacity to cope with stress measured on the basis of heart rate variability.

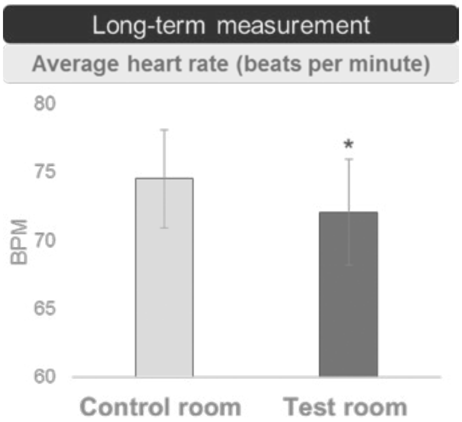

Figure 1: Average heart rate as a measure of tension/relaxation level and mental load.
The mean heart rate was significantly lower in the test room with the new lighting system.
*$p < 0.05$ Error bars attached to the columns represent standard deviation.

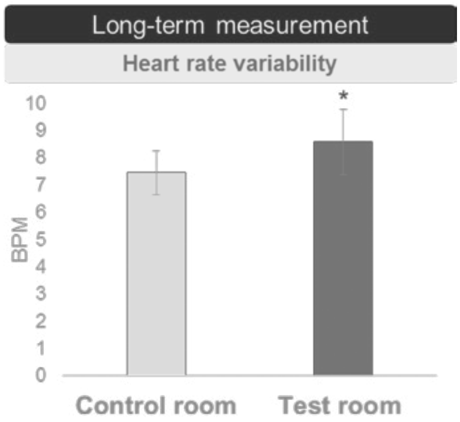

Figure 2: Heart rate variability as a measure of the psychological resilience.
The participants' capability to cope with stress was significantly better during their stay in the test room.
*$p < 0.05$ Error bars attached to the columns represent standard deviation.

Cortisol levels were assessed before and after the long-term measurement. Levels of this hormone rise and fall following a daily pattern, normally being highest in the morning and lowest in the evening. Cortisol is essential for energy and health; however, the release of this hormone is also elicited as a response to stress. A constant presence of high levels are an indication of chronic stress and anxiety. The Cortisol saliva tests provided an evaluation of how the participants' cortisol levels differed throughout the day. The results of both, the morning and the noon cortisol tests did not differ between participants and helped to rule out differences regarding the stress level of the subjects. As expected, the cortisol level decreased during the day.

b. Measurement of attentional performance

The sustained attention task of the cognitive test was applied with two objectives: Firstly, to measure the effect of both lighting systems on the attentional system, which is linked to numerous cognitive, perceptual, and motor actions. The second objective was to induce a stress situation and investigate the effect of the lighting scenarios on the psychophysiological stress-responses of the employees.

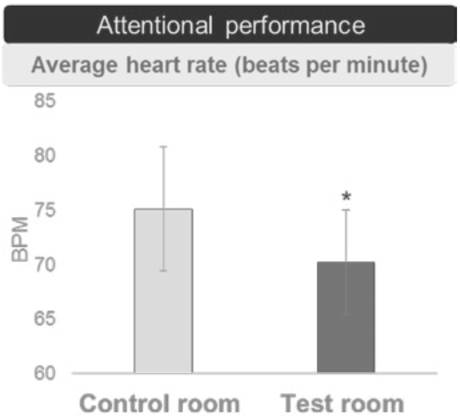

Figure 3: Average heart rate as a measure of tension/ relaxation level and mental load.
The bioadaptive lighting induced a significantly more calmed mental state during the performance of the attentional task. *$p < 0.05$ Error bars attached to the columns represent standard deviation.

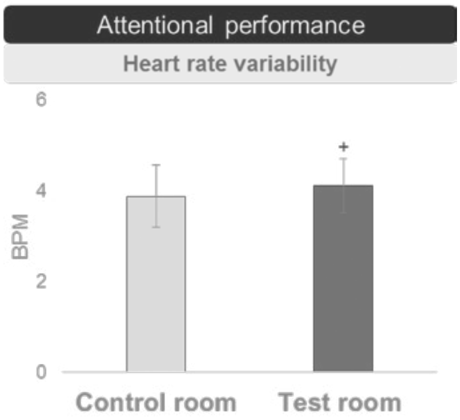

Figure 4: Heart rate variability as a measure of the psychological resilience.
Participants were significantly more capable to manage the stress elicited by the attentional task after their exposure to the new lighting solution.
$^{+}p < 0.1$ Error bars attached to the columns represent standard deviation.

Additional psychophysiological parameters were recorded during the performance of the attentional task. These parameters, in combination, evaluated the emotional and cognitive state of the participants by delivering information about the level of tension or relaxation, of attention and interest, concentration, cognitive load and about the elicited positive or negative emotionality. The recorded data was directly related to the attentional task; however, it was expected that the stay under the influence of the new lighting solution would have a positive effect on the emotional wellbeing and the cognitive state of the participants during the performance of the mentioned task.

In comparison, the stay in the room with the new lighting solution evoked a more calmed and balanced mental state. Both, the results of the psychophysiological and the cognitive data analysis showed a less negative and more relaxed state during the performance of the attentional task. Although the participants were facing a stressful situation elicited by the attentional task, they were 6.5%[1] less tense and 5.9%[2] more capable to manage the evoked stress after the influence of the bioadaptive lighting solution. Both differences were statistically significant (see Figure 3 and 4).

[1)] Tension level based on the measured mean heart rate.
[2)] Capacity to cope with stress measured on the basis of heart rate variability.

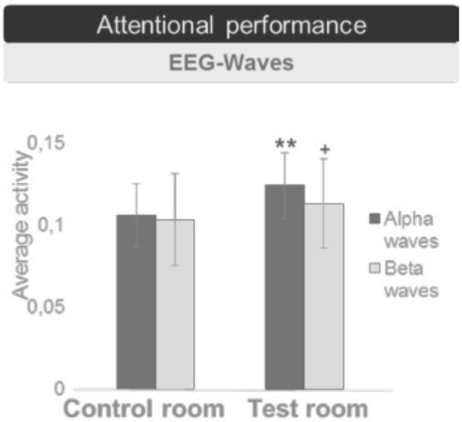

Figure 5: Alpha and Beta waves as a measure of brain activity in response to the task.
Participants were more relaxed (* $p < 0.01$) and were able to concentrate better ($^{+}p < 0.1$) during the attentional task as a result of their exposure to the new office lighting system. Error bars attached to the columns represent standard deviation.

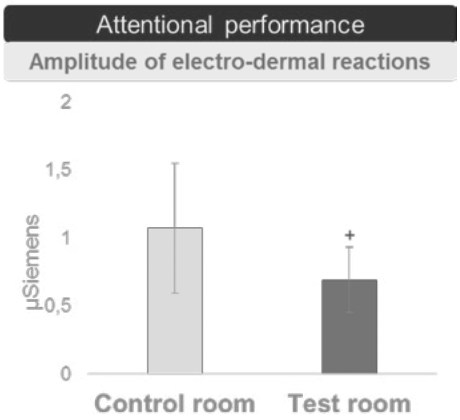

Figure 6: Electro-dermal activity as a measure of arousal and attention level during attentional performance.
Participants had a better activation level after the influence of the new biodynamic lighting.
$^{+}p < 0.1$ Error bars attached to the columns represent standard deviation.

In addition, participants were able to concentrate better and showed a more equilibrated activation level, i.e. they were attentive to the task but were less tense and had a lower arousal level (see Figure 5 and 6).

The task, although it was exactly the same on both days, elicited 23%[3] less skepticism when performed after spending the day in the test room. This difference was also statistically significant (see Figure 7).

The cognitive performance, measured based on the accuracy and speed of the responses, did not show any significant effect for neither of the lighting systems.

Furthermore, none of the lighting scenarios influenced the subjectively reported stress level.

[3)] Skepticism level as measured according to electrical activation of facial muscles.

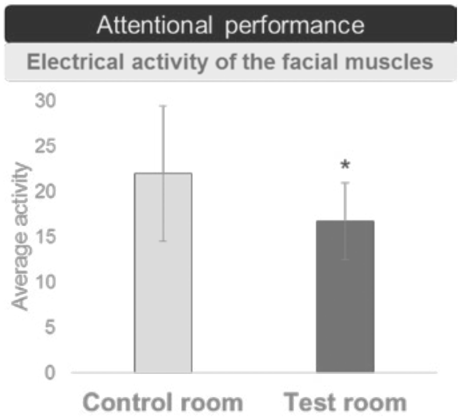

Figure 7: Electrical activity of the facial muscles as a measure of the skepticism level.
Participants responded significantly less skeptical to the same attentional task after spending the day under the influence of the biodynamic lighting.
*$p < 0.05$ Error bars represent standard deviation.

c. Summary of results and discussion

This study aimed to measure the emotional and cognitive effect of a new bioadaptive lighting system in an office environment under normal working conditions. The new lighting solution was developed based on the results of a previous study, which helped to determine the characteristics of the ideal office lighting solution (i.e. light distribution, colour temperature, luminosity and individual adjustability). To assure the objectivity of the results, the participants' psychophysiological responses to a common office lighting and to the new bioadaptive lighting were analyzed using a neuroscientific tool called Limbic® Emotional Assessment.

In summary, the tested bioadaptive lighting solution promoted a more balanced emotional state by improving the participants' well-being and reducing their arousal levels. In addition, it also had a soothing effect and increased the ability of the participants to cope with stress.

Although neither of the tested lighting scenarios had a significant effect on the reaction time and on the response accuracy of the attentional task, the participants were more focused under the influence of the new lighting system.

The obtained results show that a human-centric lighting solution in an office-working environment, not only has a positive influence on the employees' subjective emotional state, but also significantly promotes their psychophysiological wellbeing and induces a more positive emotional state.

The benefits of the new office lighting system developed by Zumtobel have the potential to go beyond the positive effect on the employees' individual emotional and cognitive state. By promoting individuals' wellbeing, in the long term, it may also increase motivation, strengthen the sense of belonging to the company and improve personal interactions between employees, generating a better working atmosphere.

6. Brief portrait of the partners

Gruppe Nymphenburg

For over 45 years, Gruppe Nymphenburg, as a consultancy and market research company, has provided services to leading international manufacturers of branded articles and trading companies, from brand positioning through to implementation at the POS.

The consultancy is based on unique consumer and shopper insights. Today, Gruppe Nymphenburg is considered one of the internationally leading experts in neuromarketing. Additionally, Gruppe Nymphenburg has been a pioneer and mastermind in the field of psychological POS and shopper research for many years.

The comprehensive expertise of Gruppe Nymphenburg opens up huge potential for enhancing buying impulses along the value chain, thus creating quantifiable added value for manufacturers, retailers and consumers.

Zumtobel

Zumtobel, a leading international supplier of integral lighting solutions, enables people to experience the interplay of light and architecture. As a leader in innovation, Zumtobel provides a comprehensive range of high quality luminaires and lighting management systems for professional interior lighting in the areas of offices, education, presentation & retail, hotel & wellness, health, art & culture as well as industry. Zumtobel is a brand of Zumtobel Group with its head office in Dornbirn, Vorarlberg (Austria).

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She is specialized in neuropsychological methods, target group and communication analyses, as well as, explicit and implicit motivational research.