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Effects of blue-enriched light on the daily course of mood, sleepiness and light perception: A field experiment

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The aim of this study was to investigate the effect of blue-enriched white light on the course of mood, sleepiness and light perception over the working day in a real work setting. The participants were 30 female office workers who were divided into two groups and exposed to two light conditions (blue-enriched white light and white light) in a counterbalanced order. Mood, sleepiness and light perception were measured three times a day on 2 days of each week. More pronounced effects of blue-enriched white light on energetic arousal were found in the morning and at midday when compared to the other times of the working day. At the beginning and the end of the work day, the workers seemed to be more sensitive to the brightness of blue-enriched white light while throughout the whole work day they seemed to be similarly sensitive to colour temperature.

1. Introduction

This study concerns the non-visual effects of blue-enriched white light (BEWL) on subjective mood, sleepiness and light perception among female office workers throughout an 8-hour working day. Both laboratory and field studies provide evidence of various non-visual responses of the human organism to blue light. Circadian, neuroendocrine and neurobehavioral responses appear to be most sensitive to blue light of 447–480 nm.[1,2] Laboratory studies have demonstrated immediate effects of blue light on subjective and objective alertness. For example, exposure to low-intensity blue and green light for 2 hours in the evening resulted in differential effects on subjective and objective measures. Compared to green light, blue light exposure was associated with increased subjective alertness, suppression of the evening increase in melatonin levels and suppression of the evening fall in body temperature.[2] Longer exposure (6.5 hours) to the same light conditions during subjective night caused lower subjective sleepiness, decreased reaction time and higher objective alertness (EEG recording) in blue light when compared to green light conditions.[3] Application of five different wavelengths of blue light resulted in increasing alertness ratings with shorter wavelengths.[4] More recently Phipps-Nelson *et al.*[5] demonstrated that even very low-intensity blue light had a potential to increase objective alertness indices (e.g. reaction time, EEG recording) during prolonged nighttime performance testing.

The potential of using light for moderating mood has been suggested by research on the effect of light therapy on seasonal affective disorder and other mood disorders.

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Indeed, many studies demonstrate positive mood effects of light therapy in those suffering depressive disorders.[6–8] The results from behavioral lighting research on the effect of different colours of light on mood assessment suggest combined effects of colour on light, gender and age.[9] A recent laboratory study demonstrated the impact of blue light on mood. Vandewalle *et al.*[10] showed that when compared to green light blue light increased brain responses to emotional stimuli.

Attention has also been paid to light perception: to how people experience and report on lighting conditions, mainly in behavioral lighting research.[11] However, it appears that there has been a lower level of interest in the psychology of light perception in laboratory and experimental field research. People at work, in their homes and at leisure are the final recipients of lighting research findings. Therefore, exploring their subjective states in response to different lighting regimens is justified in order to aid effective implementation of lighting to contribute positively to human functioning, whether in the workplace or elsewhere.

A few studies in real work settings have demonstrated that BEWL (17 000 K), when compared to neutral white light (WL) (5300 K) of the same illuminance, had beneficial effects on daytime alertness, performance and mood and on quality and quantity of sleep at night.[12,13] In another study, students were exposed to two different lighting conditions (17 000 K and 4000 K) during lectures at two different times of the year (Autumn and Spring). Compared to the lower colour-temperature conditions, students reported higher alertness at the end of lectures under higher colour-temperature light in the Autumn but not in Spring.[14]

Other studies in offices have shown less clear results of lighting conditions differing in colour temperature. Although a beneficial effect of lighting on one dimension of mood ('activity') was observed on the first day of the experiment, no continuous changes in mood could be observed at the end of three experimental days.[15] In addition, some field research has demonstrated no relationship between strictly measured daily exposure to light (level of illuminance and irradiance of blue light component) and alertness or mood.[16]

There is a shortage of applied research on the effect of exposure to blue light in real work settings throughout a whole working day. Sleepiness and mood change during the day in a circadian manner and it would be informative to explore whether or not their daily trends are differentially affected under blue light and WL conditions. Thus, the current applied study addresses the question: 'What are the differences in mood, sleepiness and light perception in BEWL (17 000 K) and WL (4000 K) conditions among female office workers throughout a working day?'

Based on the existing research evidence, the main hypotheses of this study are as follows:

1) Subjective energetic arousal (EA) will be higher and sleepiness lower during an 8-hour working day of exposure to BEWL (17 000 K) than during an 8-hour working day of exposure to WL (4000 K).
2) The workers will assess their mood as better in an 8-hour working day of exposure to BEWL (17 000 K) than in an 8-hour working day of exposure to WL (4000 K).
3) There will be differences in perception of light conditions during an 8-hour working day of exposure to BEWL (17 000 K) as compared to an 8-hour working day of exposure to WL (4000 K).

2. Method

2.1. Design

This study was a field experiment that was carried out between 14 September 2010 and 15 November 2010 at the office of an airline located in southern Poland. There were two lighting conditions differing in correlated colour temperature (17 000 K and 4000 K) but equivalent with regard to illuminance (500 lx as measured at the eye level while sitting). The participants were exposed to these two different lighting conditions in a counterbalanced order over 9 weeks. First, group A was exposed to WL) over the first 3 weeks. During the third weekend, the lighting conditions were changed to BEWL and the participants of group B joined the study. Thus, during the second 3 weeks of experiment, both groups A and B were under the study in BEWL conditions. Then, at the sixth weekend, the lighting was changed back into WL. Only the participants of group B were under the study for the last 3 weeks. The variables under study were measured three times during the participants' working day (07:15, 11:45, 14:15), twice a week (Tuesday and Thursday).

2.2. Participants

The participants were 30 female office workers (M = 28.3 years SD = 2.8 years) employed at the sales accounting department of a large airline's office. All participants were free from medical, psychiatric and sleep disorders as assessed by interview and medical examination. Their average work experience was 3.2 years (SD = 1.7 years). They worked full time (from 07:00 hours to 15:00 hours) at a computer, checking the correctness of the system sales of airlane tickets. All participants worked in an open-plan type office with an area of 600 m^2. Workstations were arranged in groups of four desks and were located at regular intervals throughout the office space. The participants were divided into two groups (A and B) and underwent exposure to different lighting conditions in an opposite order. The study was approved by the Jagiellonian University Ethics Committee and all participants gave their written informed consent prior to the study.

2.3. Lighting

Luminaires were mounted in the sub-ceiling at a height of 2.70 m. The lighting system consisted of a 120 luminaires arranged in a regular array in the sub-ceiling. Each luminaire contained four fluorescent tubes. In the BEWL condition, the light sources were fluorescent tubes (Philips Master TL-D 18 W/452 ActiViva) with a light output of 1150 lm, a correlated colour temperature of 17 000 K and a colour rendering index of 82. The average horizontal illuminance measured at eye level while sitting was 500 lx. In the WL condition, the fluorescent tubes used (Philips Master TL-D Super 80 18 W/840) had the following specification: A light output of 1350 lm, a correlated colour temperature of 4000 K and a colour rendering index of 85. The average horizontal illuminance was 500 lx as measured at eye level while sitting. Both types of fluorescent lamps had similar spectral power distribution in the medium and long wavelength ranges but differed with regard to the amount of short wavelength light (with the 17 000 K lamps emitting more short wavelength light of 420–480 nm). In the office, there were 10 ceiling-mounted skylights and windows representing 4% of the floor area located on the north side of the office. The skylights and windows were covered with opaque blinds during the study.

2.4. Measures

2.4.1. Mood

A paper and pencil version of the Polish adaptation of the UWIST Mood Adjective Check List was applied to assess alertness and mood.[17,18] The scale consists of 29 adjectives divided into 3 subscales according to three mood dimensions; energetic arousal (EA) ranging from energetic to tired, tension arousal (TA) ranging from nervous and tense to relaxed and hedonic tone (HT) ranging from pleasant to unpleasant. The adjectives are rated on a four-point scale (from 4 for 'definitely' to 1 for 'definitely not'). High EA

Table 1 Means and (standard deviations) of mood and sleepiness assessment in white light and in blue-enriched light conditions. The values for each combination of lighting condition and measurement time are based on the answers of both groups of participants given on 2 days every week for 3 weeks

Variable	White light measurement times			Blue-enriched light measurement times		
	07:15	11:45	14:15	07:15	11:45	14:15
Energetic arousal	26.36 (4.02)	28.83 (3.16)	28.01 (3.12)	28.81 (3.12)	28.04 (2.80)	27.78 (3.02)
Tense arousal	17.14 (2.64)	17.34 (2.72)	17.78 (2.67)	18.19 (3.16)	17.69 (2.75)	18.36 (3.16)
Hedonic tone	28.53 (3.47)	28.33 (3.62)	28.14 (3.41)	28.03 (4.00)	27.39 (3.26)	26.94 (3.17)
Sleepiness	4.11 (1.04)	4.21 (1.07)	4.01 (1.04)	4.21 (0.84)	4.21 (0.89)	4.71 (1.04)

and HT reflect positive emotions, high TA negative emotions. Internal consistency of the mood subscales was tested by calculating Cronbach's alpha. This is a coefficient that indicates the general reliability of a scale to measure what it is supposed to measure. Alphas between 0.70 and 0.95 would be considered more than acceptable indications of internal consistency. The Cronbach alphas for EA, TA and HT (for the Polish adaptation) were 0.75, 0.88 and 0.83 respectively.

2.4.2. Sleepiness

A paper and pencil version of the Karolinska Sleepiness Scale (KSS)[19] was used to assess sleepiness. The KSS uses a discrete scale. Participants report their level of sleepiness by responding to word descriptions from 1 (very alert) to 9 (very sleepy, great effort to stay awake).

2.4.3. Light perception

Light conditions were assessed by the light perception sheet.[11] The sheet comprises a list of nine adjectives describing parameters of light (glaring, soft, dim, bright, warm, comfort, normal, intense, cool) that are rated by participants using five-point (1–5) Likert-type scales with verbal anchors at the first point of the scale (not at all), middle point (moderately so) and the last (extremely).

2.4.4. Statistical analysis

Two factorial repeated measures analyses of variance were applied to the data. The factors were lighting conditions and measurement time. There were two lighting conditions (BEWL and WL) and three measurement times (07:15, 11:45, 14:15). All statistical analyses were conducted by application of the SPSS 17.0 statistical package.

3. Results

3.1. Mood

A significant main effect of measurement time ($F(2, 58) = 4.674$, $p = 0.023$) and a significant interaction between measurement time and lighting condition ($F(2, 58) = 7.958$, $p = 0.004$) were found for EA (Table 1). The daily course of EA in the BEWL condition differed when compared to that in the control WL condition. In the BEWL condition, EA was high at the beginning of the work day and then decreased over the course of work day. In the WL conditions, EA was significantly lower than in BEWL only in the morning ($t = -2,863$, $p = 0.008$). From morning to midday, EA sharply increased and then slightly decreased to the end of work day. At 11.45 hours and at 14.15 hours, the level of EA did not differ significantly between BEWL and WL conditions ($t = 1.680$, $p = 0.104$ and $t = 0.561$, $p = 0.579$, respectively). These results partly support the first hypothesis. The average level of EA was slightly higher in BWEL conditions when compared to WL conditions.

Measurement time had a significant main effect on TA ($F(2, 58) = 3.949$, $p = 0.027$).

Table 2 Means and (standard deviations) of light perception assessment. The values for each combination of lighting condition and measurement time are based on the answers of both groups of participants given on 2 days every week for 3 weeks

Light aspects	White light measurement times			Blue-enriched light measurement times		
	07:17	11:45	14:15	07:15	11:45	15:45
Glaring	2.26 (0.69)	2.28 (0.73)	2.27 (0.62)	2.96 (0.88)	2.65 (0.68)	2.95 (0.85)
Soft	2.68 (0.66)	2.70 (0.63)	2.62 (0.56)	2.22 (0.77)	2.12 (0.79)	2.28 (0.77)
Dim	2.13 (0.69)	2.05 (0.62)	2.06 (0.51)	1.75 (0.74)	2.25 (0.82)	1.83 (0.56)
Bright	3.19 (0.55)	3.26 (0.70)	3.19 (0.54)	3.56 (0.95)	3.23 (0.96)	3.64 (0.75)
Warm	2.97 (0.64)	2.91 (0.62)	2.83 (0.58)	2.03 (0.76)	2.33 (0.73)	2.28 (0.71)
Comfort	2.82 (0.55)	2.81 (0.60)	2.78 (0.48)	2.63 (0.77)	2.64 (0.79)	2.73 (0.72)
Natural	2.54 (0.49)	2.63 (0.62)	2.59 (0.62)	2.41 (0.86)	2.68 (0.81)	2.78 (0.83)
Intense	2.75 (0.64)	2.75 (0.72)	2.81 (0.63)	3.51 (0.96)	3.63 (0.89)	3.53 (0.82)
Cold	2.38 (0.66)	2.36 (0.83)	2.34 (0.68)	3.58 (0.93)	3.41 (0.65)	3.39 (0.83)

In both light conditions, TA tended to increase over the working day (Table 1).

A significant main effect of measurement time ($F(2, 58) = 3.627$, $p = 0.045$) and a close to significant main effect of light condition ($F(1, 29) = 3.854$, $p = 0.059$) were observed for HT (Table 1). HT tended to decrease over the day in both light conditions and was slightly but nearly statistically significantly ($F(1,29) = 3.854$, $p = 0.059$) lower in BEWL than in WL (M = 27.45 and 28.33, respectively). These results do not support the second hypothesis.

3.2. Sleepiness

A significant main effect of measurement time on sleepiness was observed ($F(2,58) = 12.487$, $p = 0.000$). There was an increasing trend in sleepiness over the day for the BEWL condition while in the WL condition, an initial increase was followed by a downward trend in sleepiness (Table 1).

3.3. Light perception

Significant interactions between lighting conditions and measurement times were observed for the seven adjectives that measured perception of the light conditions (i.e. 'glaring', 'bright', 'dark', 'soft', 'warm', 'intense' and 'cool'; Table 2). This supports the third hypothesis. The BEWL was assessed as more bright ($F(2, 58) = 3.990$, $p = 0.036$) and glaring ($F(2, 58) = 4.287$, $p = 0.030$) and less dark ($F(2, 58) = 7.668$, $p = 0.002$) than WL at the beginning and at the end of work day. At the midday assessment of these three characteristics, the two lighting conditions did not differ significantly.

The BEWL was assessed as less 'soft' ($F(2, 58) = 7.049$, $p = 0.006$) and 'warm' ($F(2, 58) = 6.597$, $p = 0.003$) and more 'intense' and 'cool' than WL at all measurement times. There were no statistical differences in assessment of the characteristics termed 'comfort' ($F(2, 58) = .848$, $p = 0.434$) and 'natural' ($F(2, 58) = 2.192$, $p = 0.121$) when comparing both lighting conditions across all measurement times.

4. Discussion

This study aimed to compare the effects of BEWL and WL on a range of subjectively reported states in relation to the course of a working day. The results showed that BEWL had a beneficial effect on EA only in the first part of the working day which partly supports the first hypothesis. EA was higher in the morning in BEWL conditions when compared to WL conditions. However, over the rest of the working day, EA showed a decreasing trend under both light conditions in accordance with its circadian rhythm.[20] Nevertheless, the general level of EA, irrespective of the time of day, tended to be higher in BEWL than in WL conditions. This is consistent with the results of other laboratory[4] and field studies[12,13] that have reported the alerting effect of blue light.

TA increased and HT decreased over the work day in both lighting conditions in accordance with their natural daily trends[20] and no effect of exposure to BEWL on their daily course was found. This means the second hypothesis of this study was not supported. Additionally, mean HT was slightly but significantly lower in BEWL when compared to WL conditions. This suggests that the applied blue-light exposure influenced mood (HT) in a direction contrary to that hypothesized and disagrees with other field research.[12,13] However, this is consistent with research carried out by Knez[11,21] demonstrating that negative mood of female participants decreased in ''warm'' low colour temperature WL and increased in 'cool' higher colour temperature WL. The opposite was true for male participants in Knez's research.

There was no effect of exposure to BEWL on subjective sleepiness which increased during the day independently of lighting conditions, which does not support the first hypothesis. It is also inconsistent with the results of other studies applying objective measures of sleepiness,[3] but as other researchers point out, subjective sleepiness ratings do not always parallel objective measures of sleepiness.[5,22]

The beneficial effect of blue light on mood (especially energetic activation) found in earlier laboratory and field studies was only partially confirmed in the present research (higher level of EA in BEWL than in WL conditions only in the morning). However, this agrees with the findings of other field studies with numbers of participants comparable to the present study.[16] The reason for this might be that the beneficial effects of blue light found in earlier research were small and achieved in strictly controlled conditions by application of rigorous experimental procedures and sensitive objective measures[3,10] or in large samples of participants.[13]

Perception of both lighting conditions varied over the working day for light descriptions such as 'glaring', 'dim', 'bright', 'soft', 'warm', 'intense' and 'cool' supporting the third hypothesis. WL was assessed comparably at all three measurement times whereas BEWL was assessed as more 'glaring', 'bright', and less 'dim' than WL at the first and the third measurement times. This may suggest higher sensitivity to the brightness of BEWL in the morning and in the afternoon compared to midday. BEWL was also assessed as more glaring and bright than WL of the same intensity in the morning and in the afternoon in a Finnish field study.[14] BEWL was perceived as less 'soft', less 'warm' and more 'intense' and 'cool' at all times of the day when compared to WL. This suggests differential sensitivity to alternative correlated colour temperatures during a working day. Interestingly, both light conditions were regarded equally natural and comfortable.

Limitations to this study included the relatively small number of participants (although repeated measures helped in this respect) and homogeneity of the group with regard to gender. Further confounding effects could have resulted from the lack of control of participants' exposure to light during their commute to work. This was countered to some extent by carrying out the study within the same season. Indeed, it is very difficult in such applied studies to manipulate personal in vivo conditions in such a way as to standardize psychological states across the sample. However, future research designs could attempt to minimize these limitations.

The differential effects of continuous exposure to BEWL during the working day on EA and on the perception of brightness of light demonstrated in this study suggest the importance of measuring different lighting conditions' effects at the same times of day. This finding needs closer examination in more strictly controlled research conducted with larger samples consisting of participants of both sexes. If future studies confirm the differential effects of continuous whole working day exposure to BEWL on EA, in particular, a practical implication is that workplaces should have lighting systems that deliver different lighting conditions at different times of day to optimize employee mood and effectiveness.

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