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The impact of light source technology and colour temperature on the well-being, mental state and concentration of shop assistants

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This study examined the impact of light source (LED and HID) and correlated colour temperature (warm-white and neutral-white) on the well-being, mental state and concentration of shop assistants. The experimental design was a 2×2 design with repeated measures and complete permutation on all factor combinations with 48 participating shop assistants. Results showed effects of the colour temperature on the well-being and mental state of the shop assistants. No effects of light source could be found for the explored variables. Warm-white colour temperature positively affects the intensity of well-being and mental state and negatively affects the power of concentration.

1. Introduction

Artificial lighting is one of the most natural things for shop assistants at their work place. As lighting and ambiance are intimately related[1] and as this combination has a volitional impact on customers, it is important for the design of shops. Nevertheless, we have examined the more or less unnoticed effect on shop assistants.[2] Depending on lighting design, illumination may have positive or negative effects on humans. Especially at the workplace, employees are exposed to the mostly subconscious influence of lighting on well-being and mood.[3] As emotions, motivation, well-being and related cognitive performance can also be influenced by light,[1] we have to think of issues such as motivation and job performance of employees[4] and also of effects on well-being itself, especially as work should be a source for health.[5] Because there are changes in technologies, such as lighting with LEDs, the effects of these technologies should be investigated more closely.

In an interesting, thought-provoking comment, Boyce said that in LED technology a lot of money has been invested and there is an enthusiasm to replace incandescents.[6] Additionally, there is a fashion to use LED technology, but there are no homogeneous research results for this technology. Because of this, it seems useful to do more research. To our knowledge, there is no study comparing the effects of LED and HID light source technology on shop assistants; therefore, it is one goal of this study to research effects on the well-being and mental state of shop assistants. Previous studies show that there are differences between LED and other lighting technologies.[7] Furthermore, different lighting technologies and different correlated colour temperatures can have effects on people.[8–10]

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1.1 Stress, strain and illumination

A major part of workplace research focuses on the effects of stress and strain on workers. Psychological stress is the total number of all detectable influences of the environment on a human being and has a psychological effect.[4] According to this, stress factors are objective parts of the work environment, which can be both positive and negative. Psychological strain is the immediate (rather than a long-term) effect of psychological stress on an individual, depending on their resources including individual coping strategies. Therefore, psychological strain can be seen as a consequence of certain stress factors of the working environment.[11] Objectively, similar stress can lead to different types of strain, depending on the individual.[12] This, therefore, means that changes in the lighting conditions of shop assistants can act as a possible stress factor and have to be the focus of interest. Suitable and adequate lighting at workplaces leads to more effective and efficient execution of work. Poor lighting can be a burden, increasing the risk of accidents, as well as stress and premature fatigue coupled with a higher error rate.[13] To investigate the effects of lighting at workplaces, it is necessary to examine the professions concerned. As it was shown in studies by Veitch,[8,14] results differ from a simulated experimental group (e.g. students) to an experimental group with real employees.

1.2 Well-being, workplace and illumination

Daniels and Harris[15] provided an overview of various studies on the relationship between job performance and well-being. They divided the research into two main approaches. The first approach examined the direct relationship of well-being and job performance. Poor psychological well-being is seen as a cause for poor performance.[16,17] The second approach examined performance as a consequence of existing work conditions and work stressors. Negative working conditions and low well-being seem to be linked.[18] Mostly, well-being is measured by two dimensions, positive and negative affect.[19–21] Staw, Sutton and Pelled[22] created a model that shows the influence of a positive affect at the workplace. This influence can be divided into three processes. First, a positive affect leads to a stronger work activity level, increasing performance and better cognitive abilities.[23–27] Second, individuals with a positive affect benefit from the positive reactions of others. They have a stronger influence on others and seem more sympathetic.[22,28–30] Third, people with a positive affect show more positive reactions towards others. They are more altruistic and cooperative.[30]

Workplaces are very often lit by artificial light sources which do not comply with ergonomic standards. Consequently, lighting can lead to a shift of the circadian rhythm, performance and well-being. Adequate lighting can eliminate subjective symptoms of negative stress and improve well-being.[31,32] According to Folkerts and Baade,[33] using artificial light sources with a high correlated colour temperature from 5500 K (Kelvin) to 6500 K in office workplaces is not recommended. This correlated colour temperature corresponds to daylight-white colour temperature. Low illumination intensity and a high correlated colour temperature seems cold, lifeless and give an unpleasant impression of the environment.[33,34]

1.3 Attention performance and environmental atmosphere

Some consequences of lighting may be lower concentration and fatigue. In workplaces, well-being and its effect on some cognitive processes are partly dependent on the correlated colour temperature of the illumination. According to Vogels,[35] the environmental atmosphere is a subjective experience through the perception of external elements and internal sensation. This experience is not necessarily connected with the actual mood, but it has the potential to affect feelings. Çakir[36] describes the ambiguity of the role of lighting in shops. To increase the sales, lighting which highlights the products is used but can be distracting and bothering for the shop assistants.

Baron, Rea and Daniels[37] showed that different colour temperatures have different effects on positive affect. After a while, the participants had a better conflict strategy and would work for free when experiencing a warm-white colour temperature. Mills *et al.*[9] showed that light sources with high correlated colour temperature (17,000 K vs. 4,000 K) could be a useful intervention to improve well-being and productivity of employees at a call-center.

1.5 Hypotheses

For the confirmatory data analysis, it was hypothesized that shop assistants who are exposed to different lighting technologies (LED/HID) or different colour temperatures (warm-white/neutral-white) experience different positive and negative well-being and mental states. In addition, it was hypothesized that there is an interaction in these effects between lighting technology and correlated colour temperature on the researched variables.

In the exploratory data analysis, we examined whether shop assistants who are exposed to different lighting technologies (LED/HID) or different colour temperatures (warm-white/neutral-white) differ in the degree of their positive and negative attention-stress performance and the evaluation of the environmental atmosphere. The interaction between lighting technology and correlated colour temperature on the aforementioned variables on shop assistants was an additional aspect.

2. Material and methods

2.1 Research design

The experimental design was a 2×2 within-subject design with repeated measures on the first and second factor. The first factor was lighting technology, which was subdivided into LED technology and HID technology. The second factor was correlated colour temperature also subdivided into two parts, warm-white and neutral-white. All shop assistants were exposed to all possible light variations while completing the questionnaires. The light variations were LED technology with warm-white colour temperature, HID technology with warm-white colour temperature, LED technology with neutral-white colour temperature and HID technology with neutral-white colour temperature. In addition, to eliminate sequence effects or spillover effects, all conditions were completely permutated. Sequence effects or spillover effects can occur when the same person is observed under several treatment conditions. Typical consequences of these effects are increasing fatigue, systematically fluctuating motivation and practice effects. To prevent this, all possible conditions were simulated in all the possible sequences.[38]

2.2 Participants and experimental conditions

The sample consists of 48 female participants (shop assistants). The participants aged 19–50 ($M_{age} = 29.60$, $SD_{age} = 8.6$) were recruited from shops in Austria and had a working experience in shops of at least three months. In Austria, most shop assistants are females (78.9%,[39]). For this reason and for methodological concerns, only female shop assistants were examined.

All shop assistants were exposed to each of the four lighting conditions while they completed questionnaires about well-being, mental state, attention-stress performance and the evaluation of the environmental atmosphere. The study was undertaken during the summer months to exclude possible seasonal effects. The research took place at the Lightlab of the Institute of Spatial Design, University of Technology in Graz in a specially prepared examination room

Figure 1. Examination room furnished and equipped as a retail (clothing) shop (© XAL GmbH)

(7 m × 4 m × 3.1 m) designed, furnished and equipped as a retail (clothing) shop (Figure 1).

The rectangular examination room was sealed and without daylight, while a door on the long side led to the vestibule. The inside walls were painted pure white and had a coefficient of reflection of 87%, while the floor was equipped with dark grey carpet with a coefficient of reflection of 5°. The examination room was subdivided into five zones. 'Zone 1' to 'Zone 4' showed pieces of clothing in different presentation variations. 'Zone 1' showed one female and one male window mannequin with gendered clothing combinations. 'Zone 2' presented a clothes rail on which different coloured jackets and hoodies were hanging. 'Zone 3' was a white tray with T-shirts and pullovers on the top. 'Zone 4' was characterized by jeans on a white shelf. 'Zone 5' was the workplace with a table, chair and a laptop on the table. The participants answered the questionnaires at the laptop and in between they were allowed to move freely. The pieces of clothing had a very strong colour contrast, jeans were in solid colours (blue shades and black shades) and jackets, pullovers and shirts were in loud colours (yellow, red, blue, turquoise, pink, green and purple). When creating the clothing combinations, warm and cold colour tones for the clothing were selected to emphasize the correlated colour temperatures when presenting the light situations. All colour tones were presented in each light situation. A large amount of the clothing was made out of cotton. During the entire study, the clothing, design and decoration of the examination room was kept constant. Only the lighting conditions were changed. The examination room had a vestibule, which was only equipped with a chair and a desk with a laptop (Figure 2).

In the examination room, the two light scenes are distinguished by the correlated colour temperature (warm-white

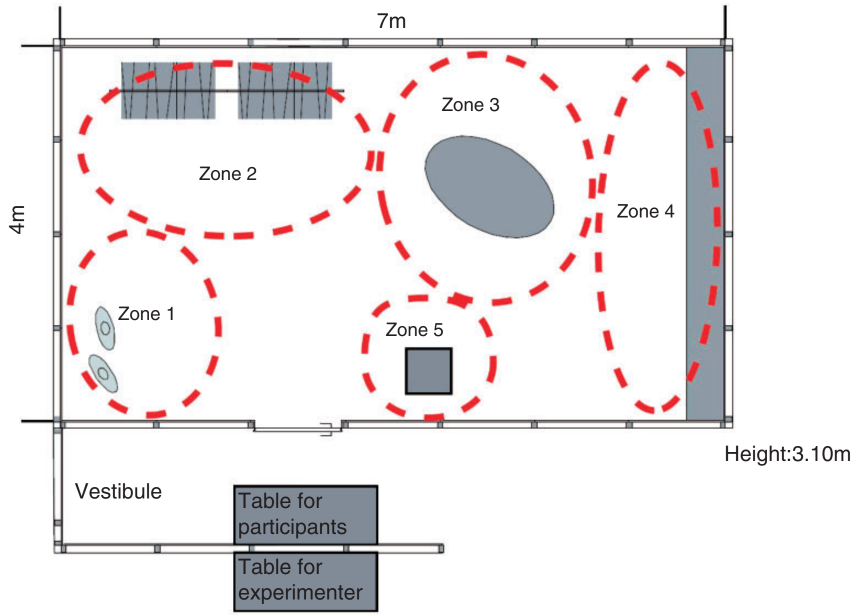

Figure 2. Different zones where participants had to go during the visit to the examination room

and neutral-white). The variation in spectrum was created by LED and HID technology. In all four light variations, the amount of light provided had to be equal, so the illuminance had to be adjusted. The examination room was exclusively equipped with four to six single moveable ceiling lights. For the warm-white light conditions, 14 LEDs (LED Cree XP-G Q5) with a correlated colour temperature of 3000 K (warm-white) and an illuminance of 1240 lx were used. Also, 14 HIDs (HID Osram HIT-CRI) with a correlated colour temperature of 3000 K (warm-white) and an illuminance of 880 lx were used. For the neutral-white light conditions, 14 LEDs (LED Cree XP-G R4) with a correlated colour temperature of 4200 K (neutral-white) and an illuminance of 1180 lx were used as well as 14 HIDs (HID Philips CDM-T) with a correlated colour temperature of 4200 K (neutral-white) and an illuminance of 720 lx. The individual arrangement and configuration of the different zones were carried out independently of the lighting and not related to the aim of luminaires. For all light variations, the spatial light distribution was room-oriented (flood lighting) using the beam spread (36°).

The illuminance distribution was measured on the floor of the experimental room at 27 points in a grid. Maximum/minimum illuminance ratio showed that the light was uniformly distributed in the examination room for all conditions (Table 1). Commercially available lamps were deliberately used in order to create a realistic experimental lighting setting. Additionally, the lamps were inconspicuous, so that visual awareness was not drawn to them. The lamps were assembled in a uniform pattern on the ceiling, so that it was possible to create a different but comparable illumination. With warm-white HIDs, UV filters were used (90% transmission) and with neutral-white HID, safety glass (91% transmission) was used. With room-oriented LED and HID lighting, the differences in the luminance distribution on the walls were slight (Table 2 and Figure 3). It is

Table 1. Summary of the measured values of colour and illuminance

Lighting technology	LED	HID	LED	HID
Colour temperature	Warm-white	Warm-white	Neutral-white	Neutral-white
Max/min illuminance ratio (measured on the floor)	2.6	2.3	2.0	1.8
Colour locus (10° observer)	$u' = 0.257$ $v' = 0.511$	$u' = 0.265$ $v' = 0.524$	$u' = 0.228$ $v' = 0.496$	$u' = 0.233$ $v' = 0.5$

Table 2. Luminance distribution of the lighting conditions (cd/m^2)

	1	2	3	4	5	6	7
LED-w	134	165	244	200	290	239	27
HID-w	118	222	262	157	234	218	28
LED-n	175	197	260	233	205	217	32
HID-n	177	192	222	257	225	273	19

Note: Positions 1–7 in Figure 3 show the luminance measurement points in the examination room.

also important to use a short exposure to the light and the examination room. If the examination period is too long, it is possible that there might be a moderating effect of adaptation.[14]

2.3 Measures

2.3.1 Well-being

The German version of the self-report affect circumplex measure Positive and Negative Affect Scale (PANAS)[5] according to Krohne *et al.*[21] was used (online version). PANAS is an instrument to assess emotional well-being, which is divided into the two orthogonal dimensions of positive and negative affect. The participants evaluate different affective adjectives about their current positive (PA) and negative (NA) mood with the help of a 5-point rating scale.

2.3.2 Mental state

Furthermore, a short version of the adjective list ('Eigenschaftswörterliste', EWL 60 S),[40] which defined self-assessment of the current well-being was applied (online version). This method is used for the multidimensional qualitative description of various aspects of mood. The participants rated the adjectives in terms of their instantaneous mood on a 4-point rating scale. The questionnaire consisted of 60 adjectives which are divided into 15 subscales, each with four adjectives. For a better interpretation, the 15 subscales are assigned to six dimensions.

2.3.3 Attention-stress

For measuring processing speed, rule compliance and quality of performance, as well as individual attention and concentration performance, the d2 Test of Attention[41] was used (pen–paper version). The test was individually accomplished within 8 minutes including the instructions and the administration. This intelligence independent concentration and attention test is an objective cross-out test.

2.3.4 Atmosphere of the environment

To evaluate the atmosphere of the examination room, an adapted version of the questionnaire Atmosphere Metrics (AM)[35,42] called Environmental Atmosphere (EA)[43] was employed (online version). This questionnaire collects adjectives using the assessment of the ambient atmosphere of an environment. The assessment is based on the emotional impact of the atmosphere of a room on the participants. On a 7-point rating scale, the participants rated the atmosphere of the environment subjectively. Of the 40 original adjectives that have been translated from the Dutch, only 16 adjectives were chosen for statistical analysis. These 16 adjectives can be classified into four dimensions (this adaption differs from the four dimensions of Vogels[35]).

Figure 3. Luminance measurement points in the examination room

2.4 Procedure

Each shop assistant started in the vestibule of the examination room, where all questionnaires were conducted for the first time. Then the shop assistants entered the examination room. In the examination room, the shop assistants took a seat and answered the questionnaire EA on a laptop at zone 5. After answering the questionnaire, the shop assistants completed a small task (counting or evaluating products) while walking through the examination room. Then they completed the EWL 60 S in zone 5, followed by a small task and the PANAS, again in zone 5. To finish, the shop assistants left the examination room and conducted the d2 test in the vestibule. While they were conducting the d2 test, the experimenter changed the lighting in the shop, which was not noticed by the shop assistants. The assessment procedure was repeated three times. Thus, each participant was tested under each lighting combination (each 11 minutes). The entire examination procedure lasted an average of 112 minutes. To counteract common sources of errors in online questionnaires, various settings that prevented skipping over the items were made.[44]

3. Results

3.1 Analysis strategy

Data analyses were carried out using SPSS 19.0 for Windows. The hypotheses on subjective well-being and mental state were calculated from four confirmatory data analysis. As the alpha-error probability increases for multiple tests on the same sample, the alpha level had to be corrected. To avoid an accumulation of alpha error, the global significance level of 5% for the confirmatory data analysis was divided by the number of confirmatory analysis (4). Because of the alpha adjustment (Bonferroni correction) for confirmatory hypotheses, the significance level was set at 1.25%.[45]

For the four exploratory data analyses, the significance level was set at 5%.[46] To test the hypotheses, univariate and multivariate analyses of variance with repeated measures were calculated (GLM-Model). To estimate the effect size, the partial eta squared was reported (η_p^2, ranges from 0 to 1), which is a common output in SPSS but is different to the classical eta squared.[47] The partial eta squared for an experimental factor is the proportion of total variation attributable to the factor, excluding other factors from the total non-error variation.[48,49] As the partial eta squared overestimates actual effect size, it should not be interpreted on benchmarks such as other effect sizes,[50] and it can be compared with the other levels of testing.[49] All results are presented in Tables 3 and 4.

The questionnaires PANAS and EWL 60 S were presented four times. To verify the hypothesis, four multivariate analyses of variance were calculated; two for the positive dimensions and two for the negative dimensions with the lighting technology and the correlated colour temperature as repeated measurement factors. The internal consistencies of the subscales of the PANAS were very good and ranged from 0.88 to 0.94. Likewise, the internal consistencies of the subscales of

Table 3. Descriptive statistics for well-being and mental state

Questionnaire	Dimension	Colour temperature				
		Warm-white		Neutral-white		
PANAS		M	SD	M	SD	*p*
	Positive affect	2.84	0.11	2.62	0.11	0.000**
	Negative affect	1.20	0.05	1.26	0.07	n.s
EWL 60 S						
	Performance-related activity	2.50	0.07	2.31	0.08	0.000**
	Extroversion–introversion	2.88	0.08	2.81	0.08	0.007*
	General well-being	2.34	0.08	2.20	0.08	0.000**
	General inactivation	1.50	0.07	1.59	0.07	n.s
	Emotional excitability	1.36	0.06	1.35	0.06	n.s
	Anxiety–depression	1.30	0.05	1.39	0.05	n.s

Note: Mean (M) and standard deviation (SD) of the subscales of the questionnaires PANAS and EWL 60 S with warm-white and neutral-white colour temperature.
n.s.= Not significant.
*$p<0.013$.
**$p<0.002$ (Bonferroni adjusted levels).

Table 4. Descriptive statistics for concentration and environmental atmosphere

Questionnaire	Dimension	Colour temperature				
		Warm-white		Neutral-white		
d2		M	SD	M	SD	*p*
	Total number of items	219.36	7.04	227.59	5.93	0.002**
	Total items minus errors	135.91	13.26	154.35	11.91	0.000**
	Concentration performance	135.03	13.29	153.45	11.94	0.000**
	Total number of errors	83.46	6.37	73.24	5.99	0.000**
	Percentage of errors	45.11	4.73	37.19	3.99	0.000**
EA						
	Coziness	3.59	0.19	3.90	0.17	n.s
	Dynamics	3.77	13.18	3.60	12.17	n.s
	Negative emotional appraisal	2.27	0.15	2.43	0.19	n.s
	Objectivity	3.18	0.12	3.45	0.14	0.002**

Note: Mean (M) and standard deviation (SD) of the subscales of the questionnaires d2 and EA with warm-white and neutral-white colour temperature.
n.s.= Not significant.
*$p<0.05$.
**$p<0.01$.

the EWL 60 S were acceptable to very good and ranged from 0.69 to 0.92. Means and standard deviations for the scales for the factor correlated colour temperature can be seen in Table 3.

3.2 Confirmatory data analysis: Well-being

Results for positive affect: The multivariate analysis showed no significant results of lighting technology (Wilks' lambda $F_{1, 47} = 1.29$, $p = 0.261$; $\eta_p^2 = 0.03$). The multivariate analysis showed a significant effect of correlated colour temperature with a remarkable effect (Wilks' lambda $F_{1, 47} = 16.94$, $p = 0.000$; $\eta_p^2 = 0.26$) on the positive affect. The interaction of lighting and the correlated colour temperature for the positive affect is not significant (Wilks' lambda $F_{1, 47} = 0.02$, $p = 0.886$; $\eta_p^2 = 0.00$). The univariate results for the correlated colour temperature showed that under warm-white colour temperature, positive affect was significantly better than under neutral-white colour temperature (see Table 3).

Results for negative affect: The multivariate analysis showed no significant results of lighting technology. The effect of the lighting technology was insignificant (Wilks' lambda $F_{1, 47} = 0.05$, $p = 0.817$; $\eta_p^2 = 0.00$). The multivariate analysis showed no significant results of correlated colour temperature and the effect was very small (Wilks' lambda $F_{1, 47} = 4.56$, $p = 0.038$; $\eta_p^2 = 0.09$). The multivariate analysis showed no significant effect of the interaction of lighting and the correlated colour temperature (Wilks' lambda $F_{1, 47} = 0.39$, $p = 0.535$; $\eta_p^2 = 0.01$). Means and standard deviations for the scales for correlated colour temperature can be seen in Table 3.

3.3 Confirmatory data analysis: Mental state

Results for positive dimensions of the EWL 60 S: The multivariate analysis showed no significant results of lighting technology and the effect of the lighting technology was very small (Wilks' lambda $F_{3, 45} = 0.23$, $p = 0.872$; $\eta_p^2 = 0.03$). The multivariate analysis showed a significant effect of correlated colour temperature with a remarkable effect (Wilks' lambda $F_{3, 45} = 7.37$, $p = .000$; $\eta_p^2 = .33$). The interaction of lighting technology and correlated colour temperature is not significant (Wilks' lambda $F_{3, 45} = 0.22$, $p = 0.885$; $\eta_p^2 = 0.03$).

The univariate examination revealed a significant effect of correlated colour temperature for the dimensions Performance-related activity (Greenhouse-Geisser $F_{1, 47} = 18.54$, $p = 0.000$), Extroversion–introversion (Greenhouse-Geisser $F_{1, 47} = 8.02$, $p = 0.007$) and General well-being (Greenhouse-Geisser $F_{1, 47} = 16.90$, $p = 0.000$). The effect of the correlated colour temperature on the subscales of the questionnaire for positive mental state is remarkable (Performance-related activity, $\eta_p^2 = 0.28$, Extroversion–introversion, $\eta_p^2 = 0.15$, General well-being, $\eta_p^2 = 0.26$). With warm-white colour temperature, the positive mental state is significantly better.

Results for negative dimensions of the EWL 60 S: The multivariate analysis showed no significant effects of lighting technology and the effect of the lighting technology was very small (Wilks' lambda $F_{3, 45} = 0.33$, $p = 0.806$, $\eta_p^2 = 0.02$). There are no significant effects of correlated colour temperature (Wilks' lambda $F_{3, 45} = 3.57$, $p = 0.021$; $\eta_p^2 = 0.19$) nor of the interaction of lighting technology and correlated colour temperature (Wilks' lambda $F_{3, 45} = 0.74$, $p = 0.533$; $\eta_p^2 = 0.05$).

3.4 Exploratory data analysis: Concentration and atmosphere

To verify the exploratory hypotheses, four multivariate analyses of variance with repeated measures (lighting technology and correlated colour temperature) were calculated; one for the positive and negative dimensions, for each of the two questionnaires.

Results for positive dimensions of the questionnaire d2: The first multivariate analysis showed no significant differences by lighting technology (Wilks' lambda $F_{3, 45} = 1{,}45$, $p = 0.240$; $\eta_p^2 = 0.09$). The multivariate analysis showed significant differences by correlated colour temperature. The effect of the correlated colour temperature was remarkable (Wilks' lambda $F_{3, 45} = 12.94$, $p = 0.000$; $\eta_p^2 = 0.46$). The multivariate analysis showed no significant influence of the interaction of correlated colour temperature and lighting technology (Wilks' lambda $F_{3, 45} = 0.64$, $p = 0.595$; $\eta_p^2 = 0.04$).

Results for negative dimensions of the questionnaire d2: The multivariate analysis showed no significant differences by lighting technology (Wilks' lambda $F_{2, 46} = 1.44$, $p = 0.246$; $\eta_p^2 = 0.06$). There are significant differences by correlated colour temperature and the effect of the correlated colour temperature was remarkable (Wilks' lambda $F_{2, 46} = 19.41$, $p = 0.000$; $\eta_p^2 = 0.46$). The interaction of correlated colour temperature and lighting is not significant (Wilks' lambda $F_{2, 46} = 0.27$, $p = 0.765$; $\eta_p^2 = 0.01$).

Table 4 reports the means (M) and standard deviations (SD) on the positive and negative dimensions of all dimensions of the questionnaire d2 on warm-white and neutral-white correlated colour temperature.

Results for positive dimensions of the questionnaire EA: The third multivariate analysis showed no significant differences by lighting technology (Wilks' lambda $F_{2, 46} = 0.47$, $p = 0.627$; $\eta_p^2 = 0.02$) and no significant differences by correlated colour temperature (Wilks' lambda $F_{2, 46} = 1.98$, $p = 0.150$; $\eta_p^2 = 0.08$). The interaction of correlated colour temperature and lighting technology is not significant (Wilks' lambda $F_{2, 46} = 1.57$, $p = 0.219$; $\eta_p^2 = 0.06$).

Results for negative dimensions of the questionnaire EA: The multivariate analysis showed no significant differences by lighting technology (Wilks' lambda $F_{2, 46} = 0.93$, $p = 0.401$; $\eta_p^2 = 0.04$). The multivariate analysis showed significant differences by correlated colour temperature with a good effect (Wilks' lambda $F_{2, 46} = 4.67$, $p = 0.014$; $\eta_p^2 = 0.17$). The interaction of correlated colour temperature and lighting is not significant (Wilks' lambda $F_{2, 46} = 0.84$, $p = 0.439$; $\eta_p^2 = 0.04$).

Table 4 reports the means and standard deviations on the positive and negative dimensions of all dimensions of the questionnaire EA on warm-white and neutral-white colour temperature.

4. Discussion

4.1 Effects of lighting technology

In this paper, the impact of lighting technologies was investigated. As there are permanent enhancements of artificial lighting technologies[51] and the awareness that light can have a positive, as well as a negative, effect on humans,[52,53] it was important to examine these possible effects. This experiment found no evidence that LED technology and HID technology differ in their effects on well-being, mental state, performance or the evaluation of the environmental atmosphere. Compared to the effect of correlated colour temperature on the independent variables ($\eta_p^2 = 0.08$–0.46), the effect of LED and HID technology ($\eta_p^2 = 0.00$–0.09) is marginal.

Any biases were carefully controlled by the design and the completely permutated conditions. The sequences of the study were standardized, so that even the experimenter effect can be seen as eliminated. A comparison to previous studies about different lighting environments is difficult. Many studies are not standardized, because they were studies in the field and not in well standardized settings, such as a laboratory.[9,10,54,55] The aforementioned studies analysed effects of correlated colour temperature. In this research, we also examined the lighting technologies LED and HID. To our knowledge, there are no other studies which compared the effects on stress for these two lighting technologies under controlled conditions.

Another tentative interpretation of the results of our study is that LED technology is not experienced as unpleasant. With a well-matched lighting-system, LED technology could be rated as equally pleasant as HID technology, at least during a short light exposure. As always with non-significant results, this has to be interpreted with caution, but our results could be a basis for further studies.

4.2 Effects of correlated colour temperature

This experiment found evidence that correlated colour temperature effects shop assistants. The effect of correlated colour temperature is very high for the positive subscales ($\eta_p^2 = 0.08–0.46$) as well as for the negative subscales ($\eta_p^2 = 0.09–0.46$). Warm-white light is visually yellow or reddish and neutral-white light appears visually bluish. According to Theiβ,[34] a warm-white colour temperature appears relaxing and cozy and a neutral-white colour temperature appears cool and objective. This could be one reason why the positive well-being and positive mental state significantly increase with warm-white colour temperature in contrast to neutral-warm colour temperature.

Especially in studies examining the relationship of well-being and lighting, there are contradictory results. Veitch[14] examined the influence of correlated colour temperatures on the well-being of 104 women and 104 men. She was using fluorescent lamps with correlated colour temperatures of 4250 K and 5000 K. The results showed no effect of the correlated colour temperatures on the subjective well-being of the participants. The results seem to be contradictory to the effects of the correlated colour temperatures found in the present research. An explanation could be that 4250 K and 5000 K are both cold and bluish-white. It seems that the differences are too small, but differences can be experienced between the two correlated colour temperature levels used in our study (3000 K vs. 4200 K).

Veitch[14] also considered that the length of the light exposure could have an influence on the effect of correlated colour temperature. In the study of Veitch *et al.*,[8] it could be shown that during a light exposure time of 50 minutes, the lamp types (including different correlated colour temperatures, 4120 K and 5000 K) affected the mood or performance of the participants. In the replication study with a longer light exposure of 3 hours, no significant differences could be recognized. Veitch[14] extended the light exposure to overcome the criticism that a shorter light exposure is not sufficient for generalizing the effects, but she found no significant differences. In our study, we again focused on the shorter period of 11 minutes. For this reason, we can tentatively not exclude the possibility that a long and a short light exposure have different effects on well-being and performance.[8,14] To accept or reject these influences of different light exposure durations, further studies with longer light exposure must be performed.

Another interesting result is that the concentration performance is significantly better with neutral-white compared to warm-white colour temperature. It seems that the concentration performance rises when the correlated colour temperature is cooler and looks more objective. A comparison of the data collected of the concentration performance in this study with other research results is hardly possible, as most of the existing results were measured with subjective questionnaires.[9] Thus, the results are not transferable. According to Boyce *et al.*[56] and Veitch *et al.*,[57] they found no main effect of illumination on concentration, even though they measured objective performance. The reason for this different result could be that they examined other variables of lighting such as direct and indirect light. Maybe a combination of both variables, correlated colour temperature and direct/indirect light including individual lighting control[52,58] would be interesting to research. Individual lighting control means that the individual is given the possibility of changing the light level, the correlated colour temperature and other light variables during the day.

It could be examined, whether, with the measurement of environmental atmosphere, the room is rated significantly more 'objective' during exposure to neutral-white colour temperature than under exposure to warm-white colour temperature. As this is an exploratory result, we have to look at it with caution. It could affirm the statement of Theiβ[34] that a neutral white colour is rated as objective. For the use of different correlated colour temperatures in a shop, the results of this study are interesting but have to be reinvestigated.

4.3 Critical aspects of the study

A different choice of colours of products or objects may have had a different influence on the effect of light.[59] In the present study, the examination room was like a real clothing shop, with different coloured clothes. To simulate the effect of the different lighting conditions in a real shop, the effect of the different colours of products was not the research focus, so in all lighting conditions the colours of the products were the same.

The participants of the study were shop assistants. To generalize the results, a further study should be undertaken with a different sample. In a study of Knez and Kers,[60] there was a different effect of correlated colour temperatures on females and males. In a continuation study, it would be interesting to test male participants.

The focus of this research was to study the impact of the environmental perception in a nearly realistic light scenario in retail settings on shop assistants. There was an attempt to keep the illuminance constant in the various conditions. However, a lot of light was reflected from the walls. That means that there were also high averaged illuminances on the floor of the examination room. Because of the arrangement of the ceiling lights, the general differences in lighting technology between LED and HID and the non-dimmable lights, it was technically impossible to reach exactly the same illuminance. When designing the lighting scenario, the focus was on a homogeneous illumination. To have a constant illumination in the room, the illuminance provided by the lamps had to be adjusted as described in Section 2.

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