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THE EFFECT OF WARM AND COOL LIGHTING ON VISUAL PERFORMANCE OF ELDERLY WORKERS

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Longer professional activity of people in aging populations forces changes in the work environment. Lighting conditions should be tuned to meet specific preferences of the elderly workers. Apart from the essential high levels of illuminance needed, a question of a proper correlated color temperature (CCT) of light seems to be worthy of consideration.

In this study, the visual performance of twenty persons aged 58-73 years old was examined in two lighting conditions provided by fluorescent lamps of CCT 2700 K and 6500 K, both lamps of color rendering index (CRI) 82. Ophthalmologic tests were applied and assessments of legibility and symptoms of fatigue were compared. Elderly people discriminated hues much better at CCT 6500 K than at CCT 2700 K. For achromatic visual tasks, a slight advantage of the CCT 6500 K light was observed. Subjective assessments favored the CCT 6500 K also. Lighting sources with high CCT seem to be better suited to elderly workers.

Keywords: elderly, visual performance, lighting, CCT, Lanthony test

1. INTRODUCTION

An aging population is a serious challenge for many societies. In the European Union's 27 member states, the share of elderly people (age 65 and over) is forecasted to increase from 17 % of the total population in 2007 to 30% in 2060. That forces changes in pension policies, including an increase of the statutory and effective retirement ages. The latter is expected to rise even by more than three years in Germany, Italy, Malta and Poland (Ageing Report, 2009).

A higher employment rate of older workers will require modifications in the work environment to compensate for their lowered physical fitness. It is a well-

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known fact that human visual capabilities deteriorate with increasing age (Birren, Williams, 1982). Besides macular degeneration and glaucoma, which are problems for many elderly people, a degradation of the image entering the eye due to opacifications in the lenses commonly occurs. With age, the lens clouds up which brings about an increased scattering of light and obstructs its access to the retina. Moreover, the pupil diameter decreases. Consequently, only 1/3 of the light reaches the retina of a 60 year old person in comparison with that of young 20 year old in the same illumination conditions (Falkowska, 1978). Thus, elderly people need higher illuminance than young ones to keep their vision efficient (Falkowska, 1978; Schierz, 2011). However, their visual performance remains always lower (Janosik et al., 2013; van Bommel, 2006). The chromatic discrimination ability of elderly persons may also be lowered because of yellowed ocular media (Boettner, Wolter, 1962), although the yellowing displays large inter-individual variability and usually concerns persons over the age of 70 (Artigas et al., 2012).

For all these reasons, various methods of visual performance improvement of elderly workers are worthy of exploration. Apart from the increased illuminance, light sources of appropriate correlated color temperature (CCT) may be applied to make visual work easier (Rautkylä et al., 2010). Preferences for reading lights have been shown to be dependent on the age of the subject. From four different light sources of CCT in the range from 2300 to 11000 K, the majority of elderly people preferred that of the CCT of 11000 K, while the younger ones decided in favor of those with CCT of 7100 and 7200 K (Yamagishi et al., 2006). On the other hand, O’Connor and Davis reported that spectral differences in three light sources of different CCT did not significantly affect the results of the Lanthony color test in two groups, one of five volunteers was aged 60 and older and two of the eight volunteers were aged 25 or younger. The younger volunteers scored much better at all types of light (O'Connor, Davis, 2005).

Apart from the CCT, the color rendition characteristics should be taken into account. That seems rather complicated, as the general color rendering index (CRI) shows limitations that are especially significant when it is applied to highly-structured spectral power distributions, such as those of fluorescent lamps or LEDs. For that reason, more sophisticated characteristics of rendering have been suggested (Houser et al., 2013), but they are not in wide use yet. Thus, the human may perceive colors differently in spite of the same CCT and CRI values of various light sources. This question includes the ability of a light source to provide a “natural” look of the illuminated objects. The latter, however, depends also on the cultural background of the observer (Liu, 2013).

Although it seems very probable that visual performance depends on the correlated color temperature of a light source, the recommended CCT is a subject of controversy (Yamagishi et al., 2008). The problem arises whether cool light should be avoided at the work stations of the elderly, as the energy is less efficiently transmitted through the older eye’s optical system by the short waves and the scattered light may cause blurred vision (Nowak, Zając, 1998) or, on the contrary, these waves ought to predominate in the light spectrum to compensate for the losses. Short waves, however, may increase the risk of age-related macular degeneration and show phototoxicity for the retina and for the retinal pigment epithelial cells (Hayashi, Hayashi, 2006). The rather low illuminances provided by artificial light sources in comparison with those of direct sunlight diminish the probability of such undesirable effects.

This work aims to compare the efficiency of elderly people performing visual tasks in warm and cool light. The studies included two types of tests: one estimated the color discrimination ability, and the second was based on the perception of monochromatic optotypes. The objective results were supplemented by a subjective assessment of visual comfort. We tried to find out whether the high-CCT light sources had advantages over the low-CCT ones that would make them worthy of recommendation for the work stations of elderly people in spite of the potential health risk.

2. MATERIALS AND METHODS

2.1. Subjects

Twenty elderly persons of a mean age of 65 years (range 58–73, standard deviation 3.7) took part in the research. Ophthalmologic examination proved that all of them showed symptoms of presbyopia, but otherwise had normal or normal-corrected vision and no visual diseases. Their color vision was tested by the use of Ishihara plates. The subjects were allowed to use their spectacles.

2.2. Lighting

The illuminance of 500 lx was provided by two sets of compact fluorescent lamps Philips Genie of electric power 14 W each that were installed on the ceiling of the testing room. Each set consisted of 14 lamps of the same correlated color temperature (CCT): 2700 K for warm light and 6500 K for cool light, according to the manufacturer. The color rendering index (CRI) was 82 for both types of lamps. The testing room had no windows, the walls and ceiling were painted white matte, and the shortest distance between the workstation and the ceiling was 2 m. During one test session, the room was illuminated either by warm, or by cool light.

2.3. Tests

Each subject participated in fifteen, ca. 30-minutes-long individual sessions of visual perception tests. The first session was a preliminary one, and its aim was to familiarize the subject with the experimental procedure. Its results were not recorded. Then, 14 sessions were performed: seven at cool and seven at warm light, in random sequence. Each test session was preceded by 10 minutes of the subject's adaptation to the illumination conditions. The session included three tests: one out of seven variants of the Bourdon test, the Landolt C eye chart examination and Lanthony D-15d test. At the end of the session, the subject assessed the legibility of the fonts printed on the Bourdon test sheets and reported symptoms of fatigue.

Modified Bourdon single letter cancellation test

2000 lower case Times New Roman letters were printed randomly in lines, without spaces in the line, line spacing 1.5, at one A4 size sheet of white paper. All letters on one test sheet had the same size and color, and showed the same contrast with the background. In the test, the subjects were asked to cross one of the stimulus letters, either "c" or "a". The number of mistakes, i.e. the omitted stimulus letters and other letters crossed in error, as well as the time taken to complete the test were recorded. The former were expressed in percentages according to the following formula:

$$E_{\mathrm{B}} = n_{\mathrm{e}} / n_{\mathrm{s}} \tag{1}$$

where n_{e} is the number of mistakes and n_{s} is the total number of stimulus letters in the test sheet. The E_{B} values make it possible to compare the results of the tests obtained using the test sheets with different stimulus letters.

Fonts of various size, contrast and color were used. Detailed characteristics are reported in Table 1.

Table 1. Characteristics of the letters printed on the Bourdon test sheets

Set #	**Font size**	**Visual angle[a]**	**Color**	**Contrast**
1	Big (14 points)	17'	Black	High (C = 0.8)
2	Medium (11 points)	13'	Black	High (C = 0.8)
3	Small (8 points)	9'	Black	High (C = 0.8)
4	Medium (11 points)	13'	Black	Medium (C = 0.6)
5	Medium (11 points)	13'	Blue (sRGB 162, 173, 212)	Medium (C = 0.5)
6	Medium (11 points)	13'	Orange (sRGB 232, 157, 99)	Medium (C = 0.5)
7	Medium (11 points)	13'	Black	Low (C = 0.3)

[a] visual angle at a distance of 40 cm

The Weber contrast was defined as:

$$C = (L_{\mathrm{b}} - L_{\mathrm{f}}) / L_{\mathrm{b}} \tag{2}$$

where L is the luminance, the subscript „b" stands for the background paper and „f" for the font.

The blue and orange font colors were based on the "purplish blue" (68, 91, 170 in the 8-bit sRGB scale) and "orange" (sRGB 224, 124, 47) color patches of the Gretag-Macbeth card (McCamy, Marcus, Davidson, 1976, Pascale, 2006). A card of that type, X-Rite ColorChecker Passport, was used to verify the printouts of the two last colors. To get the medium value of the font/background contrast, the colors were lightened to the following sRGB values: (162, 173, 212) for blue and (232, 157, 99) for orange.

Landolt C eye chart

The Landolt C eye chart is a standard test for measuring distance visual acuity. It was performed according to the standard EN ISO 8596, 2010 (EN ISO 8596:2010). The test consisted of recognizing the Landolt C optotypes i.e. rings with a gap at various positions, similar to the letter C. The tested person reported on which side of the optotype the gap was located. The smallest size of the optotypes were recorded at which the error rate did not exceed 2. The result was the Landolt fraction that might vary from 1/10 (the worst score) to 11/10 (the best score).

Lanthony's desaturated 15-hue test

The test was originally designed to diagnose mild and moderate losses of chromatic discrimination ability (Lanthony, 1978). Since the two types of the light sources applied in the present study showed the CRI equal to 82 rather than 100, it could not be used to that end, but the differences in the results of the tests performed in warm and cool light were considered. The subject arranged 15 colored caps in a sequence of similar colors of neighboring caps. This sequence and time necessary to complete the test were recorded. Two parameters were calculated: the confusion index (C-index) according to Vingrys and King-Smith (1988) and Bowman's Color Confusion Index (CCI) using the table of color distance scores reported by Geller (2001). For the perfect arrangement of the color caps, both two indices are equal to 1. The larger is the difference between the experimental and perfect arrangements, the higher are the values of the two indices.

Subjective assessments

After the tests, the subjects assessed legibility of the fonts printed on the Bourdon test sheets in the following discrete scale: 1 – very low, 2 – low, 3 – sufficient, 4 – good, 5 – very good. The subjects were also asked to report symptoms of fatigue classified in 11 categories: eye burning, sandy-gritty eye irritation, photophobia, eye twitching, blurred vision, eye pain, eye redness, excessive lacrimation, headache, nape pain, and other symptoms.

2.4. Statistics

The "Statistica" data analysis software system (StatSoft, 2011) was applied in the calculations. The dependent *t*-test for paired samples, the sign test and the Wilcoxon signed-rank test were the main tools used in hypotheses verification. In the Deming regression calculations, the non-linear regression module with the user-defined loss function was used.

3. RESULTS

3.1 Bourdon tests

The percent of mistakes was calculated according to eq. 1 for each subject and for each variant of the Bourdon test at two different lighting conditions. In this way, 7 sets of paired samples were obtained, each sample numbered 20 individual test scores. The values of time taken to complete the test were arranged in the same manner. The mean percentages of mistakes and the mean times taken to complete the test, as well as the respective standard deviations were calculated for each sample.

The dependent *t*-test for paired samples was applied for the null hypothesis that the mean value of the percent of mistakes is independent of the lighting conditions. The results are reported in Table 2.

Table 2. Descriptive statistics and results of the statistical tests for the Bourdon test scores in two lighting conditions (warm light – 2700 K, cool light – 6500 K)

Set #	**Font**			**CCT (K)**	$E_{B, CCT}$ **(%)**		$E_{B, 2700}$-$E_{B, 6500}$ **(%)**		***t*-test**		**Signs**	**Wil-coxon**
	Size	**Color**	**Contrast**		**Mean**	**Std. dev.**	**Mean**	**Std. dev.**	***t***	***p [%]***	***p [%]***	***p [%]***
1	Big	Black	High	2700	3.4	2.8	–1.4	4.4	–1.38	18.3	12.1	13.2
				6500	4.7	5.7						
2	Me-dium	Black	High	2700	7.2	6.3	0.9	3.7	1.03	31.6	45.3	21.5
				6500	6.4	5.2						
3	Small	Black	High	2700	11.0	11.9	3.9	9.1	1.91	7.1	35.9	19.8
				6500	7.1	4.8						
4	Me-dium	Black	Medium	2700	6.0	6.7	1.7	6.9	1.09	28.7	100	55.4
				6500	4.3	3.1						
5	Me-dium	Blue	Medium	2700	8.1	5.4	2.8	3.4	3.63	0.2	1.0	0.2
				6500	5.3	4.2						
6	Me-dium	Or-ange	Medium	2700	5.2	4.9	0.5	2.6	0.86	39.8	42.3	24.5
				6500	4.7	4.4						
7	Me-dium	Black	Low	2700	9.5	6.8	–0.4	5.7	–0.31	75.9	81.4	60.1
				6500	9.9	8.6						

It is evident that in five cases out of seven, the mean percent of mistakes was lower for cool illumination. However, the differences in the mistake percentages were rather small, except those for the blue font (set #5), where the probability value p = 0.2 %. That is fairly below the significance level α = 5 %, commonly accepted as a threshold value for rejecting the null hypothesis. Two non-parametric tests: the sign test and the Wilcoxon signed-rank test gave similar results. The probability values obtained in these tests are reported in Table 2.

The same statistical approach was applied to the times taken to complete the test. The results reported in Table 3 suggest that the time is independent of the CCT. That is in spite of the low p values for sets #4 and #7. Opposite signs of the differences, positive for the medium contrast and negative for the low contrast black fonts, are most probably accidental, because the two fonts are too similar to one another to account for the discrepancy.

Table 3. Descriptive statistics and results of the statistical tests for the time taken to complete the Bourdon tests in two lighting conditions (warm light – 2700K, cool light – 6500K)

Set #	Font			CCT (K)	$t_{B, CCT}$ (s)		$t_{B, 2700}–t_{B,6500}$ (s)		*t*-test		Signs	Wilcoxon
	Size	**Color**	**Contrast**		**Mean**	**Std. dev.**	**Mean**	**Std. dev.**	***t***	***p* [%]**	***p* [%]**	***p* [%]**
1	Big	Black	High	2700	575	110	–12	42	–1.29	21.3	35.9	10.3
				6500	587	120						
2	Medium	Black	High	2700	655	156	24	99	1.10	28.6	50.2	16.7
				6500	631	155						
3	Small	Black	High	2700	646	115	2	117	0.06	95.2	82.3	76.5
				6500	644	135						
4	Medium	Black	Medium	2700	607	125	31	47	2.94	0.8	11.8	1.4
				6500	576	103						
5	Medium	Blue	Medium	2700	622	140	3	60	0.20	84.0	50.2	68.1
				6500	619	137						
6	Medium	Orange	Medium	2700	592	115	–20	54	–1.64	11.7	64.6	12.6
				6500	612	122						
7	Medium	Black	Low	2700	700	190	–47	95	–2.20	4.0	4.4	2.3
				6500	747	168						

No significant correlations were found between the score and time in the Bourdon tests. The correlation coefficients varied from 0.03 for set #2 (cool light), to 0.32 for set #1 (cool light).

The legibility of the fonts assessed by the subjects, reported in Table 4, remains in good agreement with the Bourdon test results. For the blue font, the subjects decided definitely in favor of the cool illumination. The orange font was also more legible at this kind of light.

Table 4. Descriptive statistics and the results of statistical tests for the subjective assessments (*A*) of the fonts legibility at two lighting conditions (warm light – 2700K, cool light – 6500 K)

Set #	Font			CCT (K)	A_{CCT}		A_{2700}-A_{6500}		*t*-test		Signs	Wil-coxon
	Size	Color	Con-trast		Mean	Std. dev.	Mean	Std. dev.	*t*	*p* [%]	*p* [%]	*p* [%]
1	Big	Black	High	2700	3.21	1.03	–0.47	1.17	–1.76	10	39	10
				6500	3.68	0.82						
2	Medi-um	Black	High	2700	3.47	0.61	0.11	0.99	0.46	65	77	64
				6500	3.37	0.83						
3	Small	Black	High	2700	2.58	1.17	–0.42	1.07	–1.71	10	11	13
				6500	3.00	1.15						
4	Medi-um	Black	Medium	2700	3.44	0.86	–0.22	0.73	–1.29	22	34	26
				6500	3.67	0.77						
5	Medi-um	Blue	Medium	2700	2.83	0.79	–0.56	0.98	–2.40	3	10	4
				6500	3.39	0.85						
6	Medi-um	Orange	Medium	2700	2.72	0.96	–0.44	0.98	–1.92	7	6	10
				6500	3.17	0.86						
7	Medi-um	Black	Low	2700	2.40	0.75	0.30	0.92	1.45	16	15	20
				6500	2.10	0.91						

3.2. Landolt C eye chart

Nineteen out of twenty subjects performed the Landolt C vision test several times at two different lighting conditions: fourteen subjects six times (i.e. six tests in cool light and six in warm light), four seven times, and one five times. One subject did not participate in this part of the study. To make comparisons of the results possible, arithmetic means of the Landolt fractions were calculated, that eventually led to nineteen pairs of scores. Thus, the pair of scores represents averaged Landolt fractions for one subject tested at cool and warm light.

The samples were compared in the same way as the results of Bourdon tests and the results are reported in Table 5. The result of *t*-test for paired samples suggests that the null hypothesis of the test score independent of the lighting conditions can be rejected at the significance level α = 5 %. However, the sign test and the Wilcoxon signed-rank test gave higher *p* values. A slight superiority of the cool light over the warm one is illustrated by the histogram plotted in Fig. 1.

Table 5. Descriptive statistics *S* and the results of statistical tests for the numerators of the Landolt fraction and for the Lanthony's test results at two lighting conditions (warm light – 2700K, cool light – 6500 K)

Test	CCT (K)	S_{CCT}		$S_{2700} – S_{6500}$		*t*-test		Signs	Wilcoxon
		Mean	Std. dev.	Mean	Std. dev.	*t*	*p [%]*	*p [%]*	*p [%]*
Landolt	2700	8.50	1.51	-0.07	0.14	–2.14	4.6	13.1	9.1
	6500	8.57	1.48						
Lanthony (C-index)	2700	2.05	0.65	0.45	0.45	4.48	0.026	0.014	0.012
	6500	1.60	0.47						
Lanthony (CCI)	2700	1.62	0.41	0.27	0.28	4.27	0.041	0.014	0.019
	6500	1.36	0.28						
Lanthony (time)	2700	94	28	10	14	3.12	0.56	11.8	0.90
	6500	84	21						

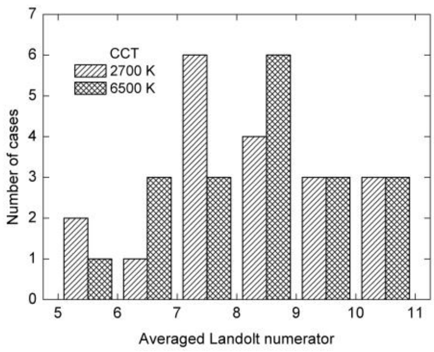
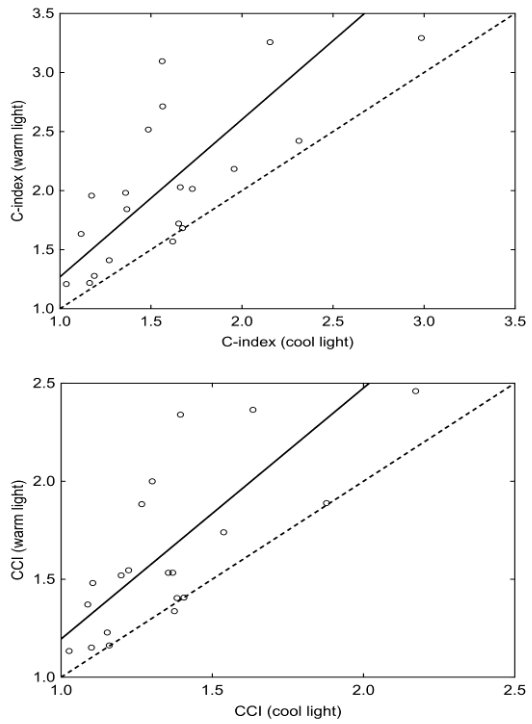


Fig. 1. Histogram of the Landolt test scores for two lighting conditions

3.3. Lanthony's desaturated 15-hue test

Twenty subjects performed Lanthony's test at two lighting conditions. Seven pairs of the results and times were collected for 18 subjects and six pairs for one subject. For one subject, six and five results were collected for cold and warm light, respectively. Two confusion indices, C-index and CCI, were calculated from the raw results. The data were treated in the same manner as those of Landolt C eye chart. In this way, 20 pairs of the mean values and respective standard deviations were obtained for C-index, CCI and time needed to complete the Lanthony's test.



Top: C-index, bottom: CCI. Points – arithmetic mean values of the indices for particular subjects; solid lines – Deming regression lines. Broken lines depict a hypothetical case of the indices independent of the correlated color temperature

Fig. 2. Correlations of the confusion indices for cool and warm light.

Statistical tests' results are reported in Table 5. The chromatic discrimination ability is much better in cool light, as is evidenced by very small p values. It is illustrated in Fig. 2, where the correlations of C-indices and CCIs for cool and warm light are plotted. Broken lines in Fig. 2 divide the plot area into two parts. The area above the broken line represents better chromatic discrimination ability in cool light, while that below the line – the opposite case. The Deming regressions were calculated using the reciprocal variances of the indices as the weights. The slope-intercept form of the line equation was slightly modified in the following manner:

$$(c_{\mathrm{w}} - 1) = (1 + a)(c_{\mathrm{c}} - 1) + b \tag{3}$$

where c is the confusion index (arithmetic mean of the C-index or of the CCI for a particular subject), subscripts "w" and "c" stand for the warm and cool light, respectively, a and b are the fitting coefficients.

For a reference state of the indices independent of the illumination temperature (broken lines in Fig. 2), the coefficients *a* and *b* would be equal to zero. That approach makes examination of the statistical significance of the empirical regression coefficients straightforward, by using the ratios of *a* and *b* to their standard errors. The results for the C-index and CCI lines are reported in Table 6.

Table 6. Statistical analysis of the Deming regression coefficients for the correlation lines of the confusion indices (eq. 3) and of the time needed to complete Lanthony's test (eq. 4)

	C-index		**CCI**		**Time**
Regression coefficient	*a*	*b*	*a*	*b*	*A*
Estimate	0.33	0.27	0.28	0.19	0.11
Standard error	0.19	0.10	0.21	0.05	0.03
t	1.78	2.60	1.36	3.73	3.26
p [%]	9.30	1.80	19.0	0.20	0.40

For both of the two lines, the *b* coefficients may be regarded as greater than zero, as $p < 5$ %. It reflects the fact that the subjects are able to discriminate the hues almost perfectly in cool light, and tend to make more mistakes when the correlated color temperature is lower. The gap between the scores obtained at cool and warm light seems to widen when the overall color discrimination ability worsens, although the *p* values above 5 % for the *a* coefficients make a clear-cut conclusion premature at this stage of the studies.

The same approach as for the confusion indices was applied to compare times needed to complete Lanthony's test, except that the regression line without an intercept was used, *i.e.*:

$$t_{\mathrm{w}} = (1 + a)t_{\mathrm{c}} \tag{4}$$

where *t* is the arithmetic mean time for a particular subject, and *a* is the fitting coefficient.

The latter and its statistical characteristics are reported in Table 6. In Figure 3, the correlation of times is plotted together with the hypothetical line representing the time independent of the illumination temperature.

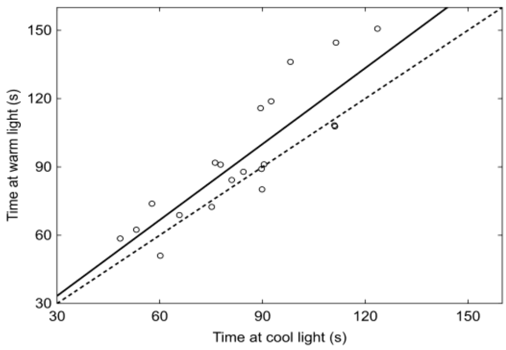


Fig. 3. Correlation of the times needed to complete Lanthony's test in cool and warm light. Points – arithmetic mean values of the time for particular subjects; solid line – Deming regression line. The broken line depicts a hypothetical case of time independent of the correlated color temperature

The time in warm light tends to be longer than that in the cool one by (11±7) % at the 95% level of confidence. This tendency was confirmed by the Wilcoxon test result (Table 6). No correlations were found between the time and the confusion indices. The correlation coefficients for the C-index are equal to –0.073 for cool illumination and 0.071 for the warm one, and for the CCI they are –0.133 and 0.003, respectively.

3.4. Subjective assessments of fatigue

No significant difference was found in the subjective assessments of fatigue after the experiments in cool and warm light. It was proven by high *p* values obtained in the signs and Wilcoxon tests, 34% and 27%, respectively (Fig. 4). Most often, subjects reported either no symptoms of fatigue or just one symptom. The more common symptoms were excessive lacrimation, blurred vision or eye burning. The blurred vision was reported more frequently at warm illumination.

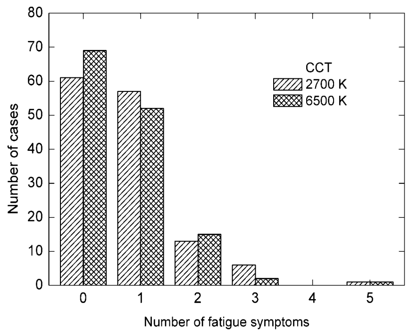


Fig. 4. Histogram of the number of fatigue symptoms reported by the subjects after the test session.

4. DISCUSSION

The reported results are evidence of the advantages of fluorescent lamps with a CCT of 6500 K over those of 2700 K for the lighting of elderly persons' workstations. Color discrimination was much better in cool light, as was illustrated by the comparison of the confusion indices plotted in Fig. 2. Moreover, the average time necessary to complete Lanthony's test was shorter in cool light than in warm light (Fig. 3). That was confirmed by the probability levels well below 5 % in the statistical tests of the differences between the results for cool and warm light, reported in Table 5. The mistakes made by subjects in Lanthony's test under warm light were mainly such as those typical of tritanomaly, *i.e.* they pointed to an impairment in the discrimination of blue hues.

This result was opposite to that reported by O'Connor and Davis (2005), who did not observe correlations between the CCT of the light sources and the results of Lanthony's test performed by young and elderly people. That might be due to the relatively low CCT of the three light sources used in their studies: 150 W tungsten halogen lamps with a CCT of approximately 2900 K, 3000 K rare-earth phosphor compact fluorescent lamps, and 5000 K "full-spectrum" compact fluorescent lamps, while the "cool" light in our study showed a much higher CCT of 6500 K. That explanation is supported by the very close values of the error scores in Lanthony's tests obtained in this study for warm light and those reported by O'Connor and Davis (2005). The mean values of the scores, defined in the way proposed by Boyce and Cuttle (1990), were 24.00, 28.20 and 22.20 for the illuminance level 700 lx and the CCT of 2900, 3000 and 5000 K, respectively. In our study, the mean Boyce and Cuttle error score was 24.54 for the CCT of 2700 K, while it was much better, 14.13, for the CCT of 6500 K. *Nota bene* the Boyce and Cuttle scores calculated from our results showed a similar correlation as those for the two other color confusion indices plotted in Fig. 2.

Although the majority of the Bourdon test results and the Landolt C eye chart scores for the light of CCT 6500 K and 2700 K did not show differences at the significance level $p < 5$ %, both the objective results and the legibility of fonts, characterized by the mean values of the respective parameters, were usually slightly better for cool light. That may suggest improved visual ability of the subjects at cool light and suggests higher visual comfort provided by this lighting (*cf.* Tables 2–5). Evidently, the short waves scattering in the eye's optical system have not caused a pronounced blurring of vision. Moreover, the symptoms of fatigue caused by the visual work were reported more often for light with a CCT of 2700 K than for that of 6500 K. The total numbers of the symptoms were 96 and 87, respectively, with the distributions shown in Fig. 4. Surprisingly, blurred vision occurred more often in warm lighting. Thus, the increased scattering of short waves in the eye system seems to be rather unimportant for the visual work performance and comfort of elderly workers. However, it should be carefully verified whether the last conclusion is valid also for people older than those examined in this study, because human visual ability rapidly deteriorates over the age of 60 years (Artigas et al., 2012). Our results are consistent with those of Wolffsohn et al. (2000), who studied effects of yellow lenses used in sunglasses on visual acuity and color vision of young subjects. The color perception due to yellow filters was impaired, usually leading to tritan (blue-yellow) type defects, while the white on black contrast sensitivity remained unaffected. The detriment in color vision due to lighting of lower CCT observed in our studies closely resembles the effect caused by yellow lenses.

The above analysis leads to the conclusion that light of high correlated color temperature should be applied at workstations of elderly people, especially where color discrimination is demanded. That agrees with the results of Yamagishi et al, who have found the light of CCT above 5000 K suitable for elderly persons (Yamagishi et al., 2008).

It must be noted that the question of proper illumination of workplaces for elderly workers cannot be reduced to the performance of visual work. The light of CCT below 3000 K decreases the activity of the central nervous system (Noguchi, Sakaguchi, 1999). High CCT lighting may improve circadian rhythmicity of persons suffering from dementia and positively influence restless behavior (Wolffsohn et al., 2000). Aesthetic and emotional judgments that decide about mood and comfort cannot be neglected. Flexible lighting systems of workplaces that provide illuminance level and correlated color temperature controlled by workers themselves, according to their needs and preferences, seem to be a reasonable solution (Manav, 2007). Probably such systems with mixed light sources of high and low correlated color temperatures are optimal at the present state of knowledge, as they make it possible to reduce unnecessary exposition to "cool" light. That is important at least as long as the problem of potential phototoxicity of short light waves emitted by modern light sources remains unsolved, especially their role in the stimulation of age-related macular degeneration (Algvere, Marshall, Seregard, 2006).

5. CONCLUSIONS

Analysis and discussion of the obtained results led to the following conclusions:

– elderly people discriminated hues much better at cold light illumination (CCT 6500 K) than at the warm one (CCT 2700 K), in spite of the same CRI of the two types of fluorescent lamps. Warm lighting often led to impaired vision resembling tritanomaly;

– achromatic and monochromatic visual tasks were performed with similar accuracy, independently of the correlated color temperature. However, a slight advantage of the cool light was observed in the majority of cases;

– light of higher CCT generally improved the visual performance of elderly people. The increased scattering of short waves in the optical system of the eye did not cause blurred vision, or this effect was too small to interfere with the performed visual tasks.

LITERATURE

1. Ageing Report (2009). *Economic and budgetary projections for the EU-27 Member States (2008-2060),* EUROPEAN ECONOMY 2, European Communities, DOI 10.2765/80301.
2. Algvere, P.V., Marshall, J., Seregard, S. (2006). Age-related maculopathy and the impact of blue light hazard, *Acta Ophthalmol Scana*, 84(1), 4-15.
3. Artigas, J.M., Felipe, A., Navea, A., Fandiño, A., Artigas, C. (2012). Spectral Transmission of the Human Crystalline Lens in Adult and Elderly Persons: Color and Total Transmission of Visible Light, *Invest Ophth Vis Sci*, 53, 7, 4076-4084.
4. Birren, J.E., Williams, M.V. (1982). A perspective on Aging and Visual Function. In: *Aging and Human Visual Function*, Alan R. Liss, Inc. 150 Fifth Avenue New York (NY), 10011, 9-19.
5. Boettner E.A., Wolter, R. (1962). Transmission of the ocular media. *Invest Ophth Vis Sci*, 1, 776-783.
6. Boyce, P.R., Cuttle, C. (1990). Effect of correlated color temperature on the perception of interiors and color discrimination performance. *Lighting Res Technol*, 22, 16-36.
7. EN ISO 8596:2010: *Ophthalmic optics. Visual acuity testing. Standard optotype and its presentation*.
8. Falkowska, Z. (1978). *Ophthalmology*. Warszawa: PZWL.
9. Geller, A.M. (2001). A table of color distance scores for quantitative scoring of the Lanthony Desaturate color vision test, *Neurotoxicol Teratol*, 23, 265-267.
10. Hayashi K., Hayashi H., (2006). Visual function in patients with yellow tinted intraocular lenses compared with vision in patients with non-tinted intraocular lenses, *Brit J Ophthalmol*., 90, 1019-1023.
11. Houser, K.W., Wei, M., David, A., Krames, M.R., Shen, X.S. (2013), Review of measures for light-source color rendition and considerations for a two-measure system for characterizing color rendition, *Opt Express*., 21, 8: 10393-10411.
12. Janosik, E., Marzec, S., Łaciak, M., Nowicka, J., Zachara, J. (2013), Assessment of the lighting conditions impact the visual efficiency of elderly workers, *Przegląd Elektrotechniczny*, 7, 2012-2014. Polish.
13. Lanthony, P. (1978). The desaturated panel D-15, *Doc Ophthalmol*., 46, 185-189.
14. Liu, A., Tuzikas, A., Zukauskas, A., Vaicekauskas, R., Vitta, P., Shur, M. (2013), Cultural Preferences to Color Quality of Illumination of Different Artwork Objects Revealed by a Color Rendition Engine, *IEEE Photonic J*., 5, 4, 6801010: 1-11.
15. Manav, B. (2007), An experimental study on the appraisal of the visual environment at offices in relation to colour temperature and illuminance, *Build Environ*., 42, 979-983.
16. McCamy C.S., Marcus H., Davidson J.G., (1976), A Color-Rendition Chart. *J App Photogr Eng*., 2, 95-99.
17. Noguchi, H., Sakaguchi, T. (1999). Effect of illuminance and color temperature on lowering of physiological activity. *App Human Sci*., 18(4), 117-123.
18. Nowak, J., Zając, M. (1998). *Optics. Elementary course.* Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej. Polish
19. O'Connor, D.A., Davis, R.G., (2005). Lighting for the Elderly: The Effects of Light

Source Spectrum and Illuminance on Color Discrimination and Preference. *LEUKOS (The Journal of the Illuminating Engineering Society of North America)*, 2(2), 123-132.
20. Pascale, D., (2006), *RGB coordinates of the Macbeth ColorChecker*, Complete update June 1st.
21. Rautkylä, E., Puolakka, M., Tetri, E., Halonen, L. (2010). Effects of Correlated Colour Temperature and Timing of Light Exposure on Daytime Alertness in Lecture Environments. *JLVE (Journal of Light and Visual Environment)*, 34, 2, 59-68.
22. Schierz, C., (2011). Lighting for the elderly: Physiological basics and their consequences. *Light Eng*., 19, 2, 19-27.
23. StatSoft (2011). Inc. STATISTICA (data analysis software system), version 10. www.statsoft.com.
24. van Bommel, W. (2006). Dynamic lighting at work, both in level and colour, Proc. 2nd CIE Expert Symposium, Canada Ottawa, 62-64. Retrieved from http:// www.solg.nt/data/userfiles (accessed 2014 February 16).
25. van Hoof, J., Aarts, M.P.J., Rense, C.G., Schoutens, A.M.C. (2008). Ambient bright light in dementia: effects on behaviour and circadian rhythmicity. *Build Environ*., 44(1), 146-155.
26. Vingrys, J., King-Smith, P.E. (1988). A Quantitative Scoring Technique For Panel Tests of Color Vision. *Invest Ophth Vis Sci*., 29, 50-62.
27. Wolffsohn, J.S., Cochrane, A.L., Khoo, H., Yohimitsu, Y., Wu, S. (2000). Contrast Is Enhanced by Yellow Lenses Because of Selective Reduction of Short-Wavelength Light. *Optometry Vision Sci*., 77 (2), 73-81.
28. Yamagishi, M., Kawasaki, F., Yamaba, K., Nagata, M. (2006). Legibility under reading lights using white LED, *St Health (Gerontechnology)*, 5 (4), 231-236.
29. Yamagishi, M., Yamaba, K., Kubo, Ch., Nokura, K., Nagata, M. (2008). Effects of LED lighting characteristics on visual performance of elderly people, *St Health (Gerontechnology)*, 7(2), 243.

WPŁYW CIEPŁEJ I CHŁODNEJ BARWY ŚWIATŁA NA WYDOLNOŚĆ WZROKOWĄ STARSZYCH PRACOWNIKÓW

Streszczenie

Coraz dłuższa aktywność zawodowa ludzi w starzejącym się społeczeństwie wymaga dokonywania zmian w środowisku pracy. Do możliwości psychofizycznych starszych pracowników powinny być dostosowywane m.in. warunki oświetleniowe. Oprócz konieczności zapewnienia wysokich poziomów natężenia oświetlenia, należałoby również zapewniać odpowiednie temperatury barwowe (CCT) stosowanych źródeł światła. W przeprowadzonych badaniach określono wydolność wzrokową 20 osób w wieku 5875 lat, pracujących przy świetle lamp fluorescencyjnych o wskaźniku oddawania barw (CRI) równym 82 oraz temperaturach barwowych CCT = 2700 K i CCT = 6500 K. Wykonano kilka testów okulistycznych, oceniano czytelność tekstu oraz samopoczucie pracowników. Stwierdzono, że osoby starsze przy świetle o CCT = 6500 K zdecydowanie lepiej rozróżniają kolory, nieznacznie lepiej wykonują achromatyczne testy, a także korzystniej oceniają swoje samopoczucie. Źródła światła o wyższych CCT wydają się zatem korzystniejsze do stosowania na stanowiskach pracy osób starszych.

Słowa kluczowe: starsi ludzie, wydolność wzrokowa, oświetlenie, CCT, test Lanthony'ego