Semantic resonance to light sources of different correlated colour temperature

Pietro Fiorentin[1], Osvaldo da Pos[2], Elena Pedrotti[1], Ariella Metellini[3]

[1] *Department of Industrial Engineering, University of Padua. pietro.fiorentin@unipd.it, pedrotti.e@gmail.com*

[2] *Department of General Psychology, University of Padua. osvaldo.dapos@unipd.it*

[3] *National Institute of Nuclear Physics, Padua. ariella.metellini@pd.infn.it*

Corresponding author: Osvaldo da Pos (osvaldo.dapos@unipd.it)

ABSTRACT

New light sources are nowadays used as a consequence of energy saving problems and developments of illumination technology. Their quality is evaluated in terms of their rendering capabilities and of people preferences. The research is focused on the psychological reaction of young participants to the environmental lighting of three rooms expressed by subjective measures of a list of associable qualities. We then describe how observers can distinguish different qualities of interior lightings. One room was lighted by a halogen lamp, and two other rooms by LED lamps. Walls were white and a rather large coloured Mondrian was hung at a wall. A group of 370 high school students volunteered in the experiment. Their task was to evaluate the quality of the three illuminations by using a semantic differential. Evaluations were performed in small groups or individually, and data were collected for each participant. Many students left the experiment after performing their task in one or two rooms only. Therefore, data from 197 students who completed the task in all the three rooms were considered. An ANOVA shows that the halogen lamp receives evaluations significantly different from the other two light sources. The two LEDs received equal evaluations in seven scales and significantly different in other three scale. A factorial analysis identifies three factors; in relation to all of them the halogen lamp significantly differs from the LEDs, while the two LEDs differ one from the other only in two factors. In conclusion naive young participants can consistently evaluate personal psychological reactions to lights and discern the qualitative features of the lightings; evaluations are not consistent with the differences in CCT of the three sources but seem affected by other lighting characteristics; some evaluations seem to depend on participants' psychological context.

KEYWORDS LED, CCT, lighting quality, psychological reaction, semantic differential

RECEIVED 15 September 2018; **REVISED** 10 June 2019; **ACCEPTED** 27 June 2019

CITATION: Fiorentin, P., da Pos, O., Pedrotti, E., & Metellini, A. (2019). Semantic resonance to light sources of different correlated colour temperature. Color Culture and Science Journal, 11(1), 74–81. https://doi.org/10.23738/CCSJ.110109

1. Introduction

We are today aware that on the one side energy resources are limited, and on the other side energy production goes with more or less detrimental alterations of the environment. The actual and universal problem is then how to prevent environmental damages by reducing energy consumption without worsening machinery performances. In the specific case of light production, we face the challenge of maintaining good quality of artificial light by developing new technologies to spare electricity consumption. If technological problems are to be solved inside engineer frames of reference, evaluation of the light quality involves psychological disciplines since the final user is the human observer.

Research in the field of illumination covers a very wide spectrum of topics, roughly divided between physical factors and psychological effects, many times both. The subjective aspects of illumination, that is the psychological reactions to the different variables characterising both indoor and outdoor llighting, become more and more relevant because the final users are human persons. Some research works are addressed to general aspects of environmental illumination (CIE 212:2014; Sansoni, Mercatelli, Farini 2015), other research deal with diffuse vs accent illumination or their interaction (Tantanatewin, Inkarojrit 2016), interactions between surface colour and illumination, illumination for different purposes (Jin et.al. 2015), CCT and CRI (Farini 2015). A critical item in many researches is the use of simulation (scenes projected in a screen, Tantanatewin, Inkarojrit 2016) vs real environment (a small room in Jin et al. 2015).

We are also conscious that various illumination devices differently affect colour appearance and the problem of evaluating the perceived quality of the light sources arises not only in terms of their rendering capabilities but also of people preferences (Thornton 1974; Yildirim et al. 2011). This research aims to describe how observers can distinguish different interior lightings in terms of their own peculiarities and of the psychological effects they generate in people.

2. The experiment

The experiment was performed in the frame of the cultural event "EXPERIENCING: an Interactive Scientific Exhibition - Energy and Life", held in Padua in 2015, inside the series of annual events "EXPERIENCING" which started in 2002 to promote science in higher grade schools.

2.1. *Participants*

About 10000 students attended the one month event and about 370 students, nearly half male and half female, from 15 to 19 years old, agreed to be accompanied by a guide and take part in the experiment. They could perform the experiment either singularly or in small groups of 10 people on the average. As many participants left the experiment before judging the lightning of all the three rooms, only data from the 197 participants who completed the experiment were used in the analysis.

2.1. *Material*

The experiment was carried out in three small rooms (about 2 x 3 m) with white walls (Figure 1); in each room a coloured Mondrian (50 x 50 cm) was hanging on one of the longer wall and a computer with a CRT monitor was placed on a small white shelf fastened horizontally on a short wall. The monitor was used to show the items of a semantic differential and record the participants' answers. The luminaires were placed above the door facing the other short wall. Three kind of light sources were installed, one halogen lamp, one medium CCT (Davis and Ginther, 1990) LED lamp, and one higher CCT LED lamp with the characteristics shown in table 1. As usual, halogen source presents a more diffuse light, while LEDs are a bit more directional, even if in any case the light direction is controlled either by a reflector or by lenses. This fact is highlighted by the lowest illuminance value for the haloghen source.

In the entrance room a commercial viewing booth with different light sources was placed on a table; a large poster was hanging on the wall above and showed the main characteristics of the cabinet sources and the ways of measuring them by appropriate instruments.

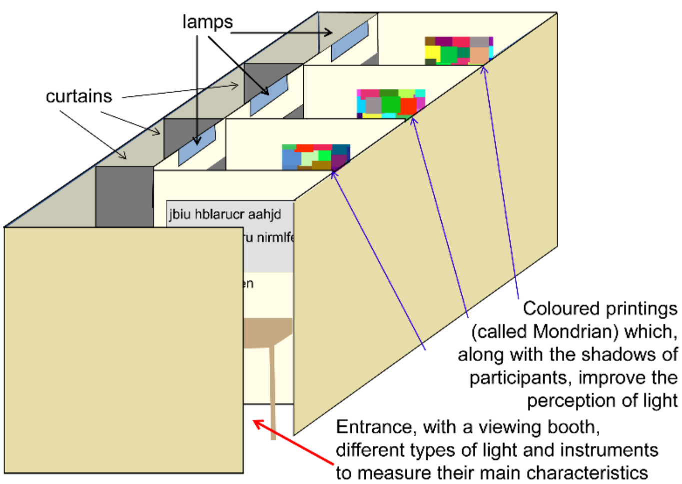

Fig. 1. The rooms where the experiment has been performed.

room	source	Watt	CCT	CRI	lm	lx on the wall	efficiency
1	halogen	150	3000K	98	3000	about 400	21 lm/w
2	LED-A	35	3080K	80	3100	about 500	89 lm/w
3	LED-B	35	3890K	80	3230	about 600	92 lm/w

Tab. 1. Specifications of the three light sources.

The evaluations of the lights illuminating the rooms were performed by using 10 verbal semantic scales (CIE 212: 2014; Osgood et al. 1957; Snider and Osgood 1969). Four scales were referring to the observer feelings: 1) calm – agitated; 2) relaxed – tense; 3) speedy – slow; 4) passive – active (original Italian scales: calmo – agitato; rilassato - teso; veloce - lento; passivo - attivo). The other six scales were referring to the characteristics of the light: 5) interesting - boring; 6) strong – weak; 7) warm – cold; 8) desirable – undesirable; 9) brilliant – dull; 10) violent – soft (original Italian scales: interessante – noiosa; forte – debole; calda - fredda; desiderabile – indesiderabile; brillante - smorta; violenta – gentile).

The items were presented in the monitor screen with an invitation to save the subjective evaluations. Participants could move a slider in the position between the two extremes which expressed their choice in the scale continuum; their decision was therefore based only on the visual appreciation of the two distances of the slider from the extremes (Figure 2). Later that position was decoded as a measure of the distance from the two extremes (in the example the slider shows a choice of 80% calm vs 20% agitated).

Fig. 2. The display used to register the participants' evaluations of the semantic differential.

2.3. *Procedure*

First, participants were led to the entrance of the experimental place and shown different kinds of illumination inside a viewing booth. Then the guide taught them about the main features of those light sources, like the physics of the production of the light, the measure of its power in watt, its luminous flux in lumen, its correlated colour temperature in kelvin, and its luminous efficiency. Lastly participants were instructed about their task which was to give a subjective evaluation of the quality of three different lights in three rooms, and that this evaluations would be structured in a series of bipolar scales of adjectives referring both to the quality of the light and to the feelings they would experience under that light. Their answer had to be expressed by appropriately using the mouse. The three rooms were visited in random order and at the end they could leave their email address to receive the results of the research.

3. Results

3.1. *Analysis of variance*

The three room illuminations (Figure 3) were globally judged significantly different ($F_{2,392} = 93{,}14$, $p < 0.00001$). Specifically, the halogen illumination was judged significantly different from the LED-A ($p < 0.00001$) and from the LED-B ($p < 0.00001$), while the LED-A source did not appear significantly different from the LED-B source ($p > 0.421$).

Of course, the scales were evaluated in a significantly very different way ($F_{9,1764} = 18.53$, $p < 0.00001$), but there was an important interaction between scales and sources ($F_{18,3528} = 101{,}09$ $p < 0.00001$), which is of great interest for the purpose of the experiment.

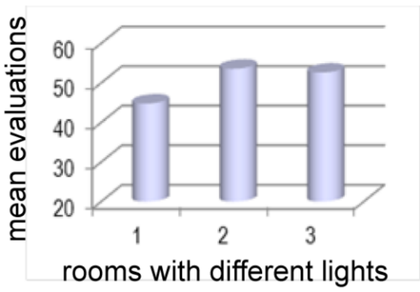

Fig. 3. Global evaluation of the three illuminations.

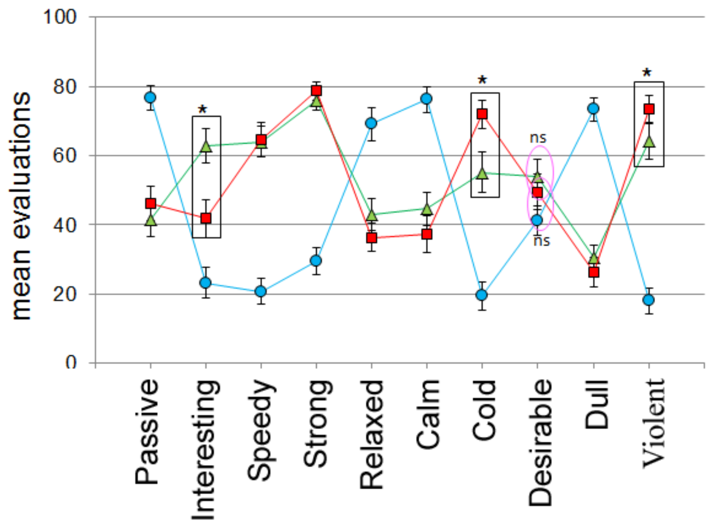

Fig. 4. Mean evaluations given by the participants to the semantic scales as a function of the three light sources. Blue circles: halogen lamp; green triangles: LED-A; red squares: LED-B.

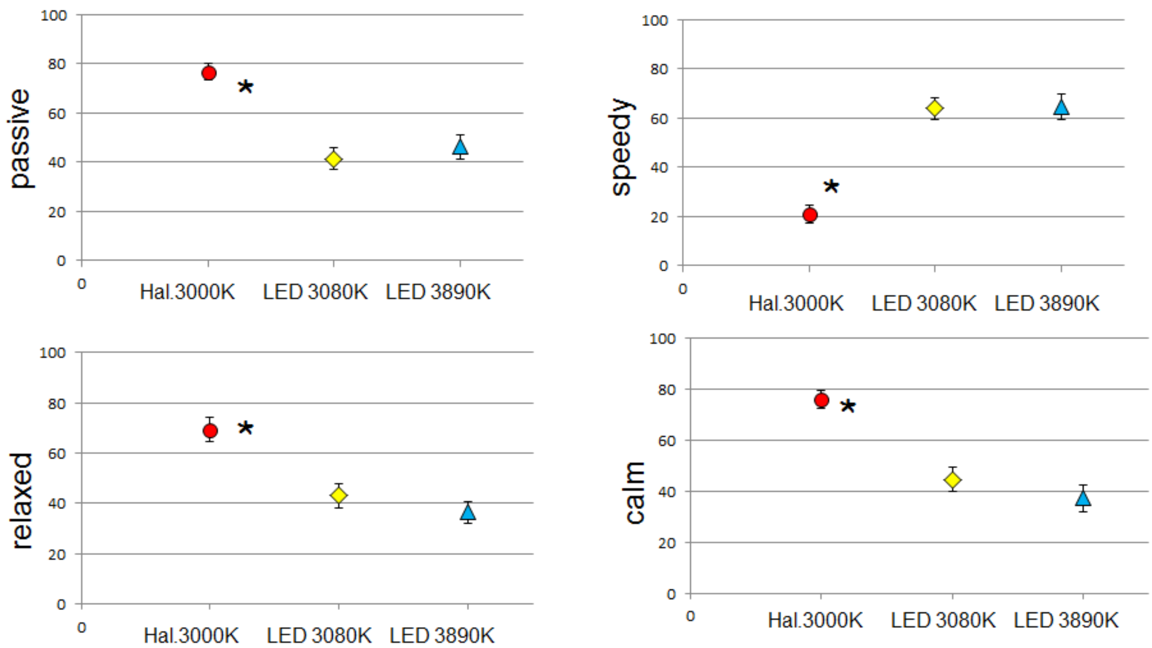

Fig. 5. Mean evaluations of the subjective effects elicited by the different light sources on the observers. Error bars = confidence intervals (mostly hidden by symbols). Stars = significantly different ($\alpha < 0.05$).

An overall view of the interactions between lights and semantic scales is presented in Figure 4, where the halogen light is connoted in a very different way from the other two LED sources, which on the other side show some differences one from the other.

An analytical presentation of the results relative to the single scales is following to show how participants exhibit different reactions as a function of the different light sources.

Figure 5 shows the results of an analysis of variance (ANOVA) relative to the psychological effects induced by the tested lights as they were evaluated by the participants. The data are derived from the answers to the question “How does this light make you feel?”. From the results it appears that the halogen illumination is perceived as inducing a state of more serenity ($p < 0.00001$), calmness ($p < 0.00001$), relax ($p < 0.00001$), passivity ($p < 0.00001$) in opposition to the LED lights which are judged to elicit tension, excitement, swiftness, dynamism. On the other side both LED lights are similar in these psychological effects.

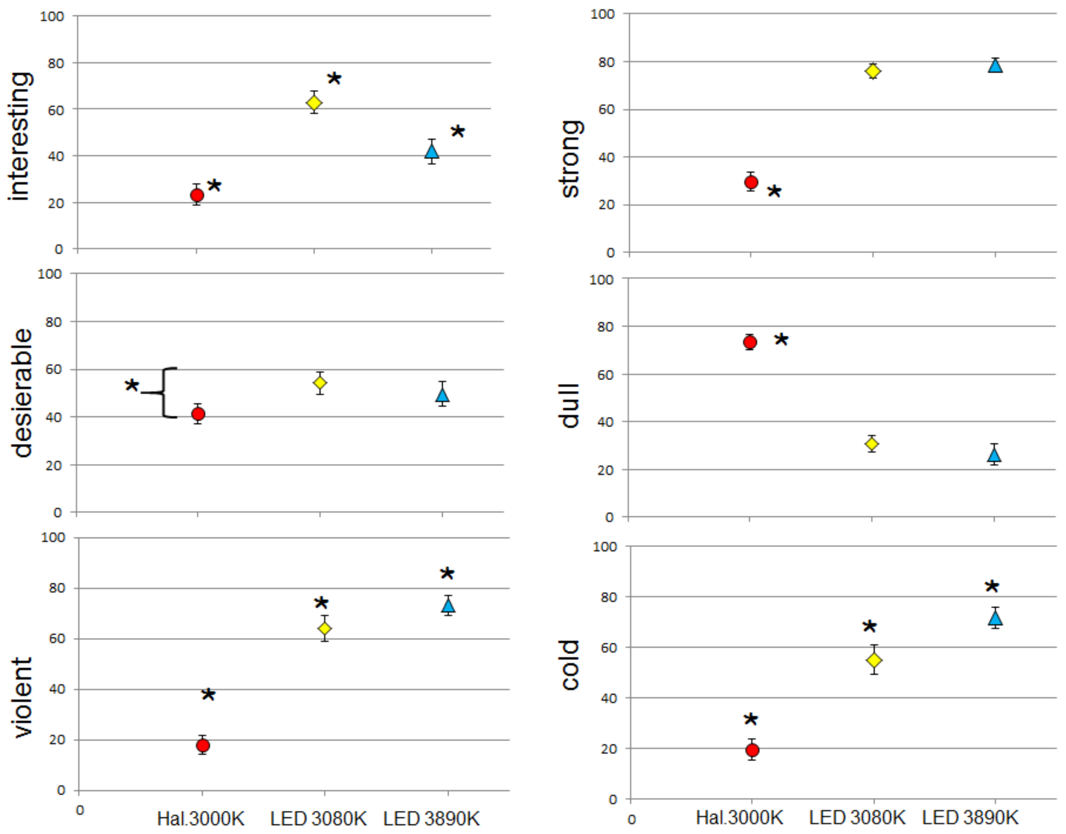

Fig. 6. Mean evaluations given by participants relative to the characteristics of the different light sources. Error bars = uncertainty intervals (mostly hidden by symbols). Stars = significantly different (α < 0.05). Braket= the significantly different pair.

These results are in agreement with what can be expected in relation to the halogen light source, whose rather warm light is largely preferred by most people in interior environments, where it gives an intimate atmosphere, and favour convivial, comfortable, tender interpersonal relationships. The association with candle lights, flames in the fireplace, or sunset light is based on the similar psychological effects they initiate. On the other side cool light as that often emitted by LEDs is generally considered unfriendly, although stimulating and speeding up, and therefore considered positive in specific circumstances. It is worth to note, even if CCT is a very important factor in driving people feeling, it is not the only cause. There are other factors to consider also in our experiment, one of them is the uniformity of the light. Differences between the results related to the considered sources can be partially associated also to the more uniform and soft lighting provided by the halogen source, with respect to LEDs.

Figure 6 shows the results relative to the qualities which participants ascribed to the different lights. The data are derived from the answers to the question “How do you estimate this light?” followed by the corresponding semantic scales Again the halogen illumination is perceived quite differently from the other LED illuminations, but at their turn these are not always judged in the same way. The halogen illumination always appears significantly less interesting ($p < 0.00001$), weaker ($p < 0.00001$), warmer ($p < 0.00001$), less desirable ($p < 0.00001$), duller ($p < 0.00001$) and softer ($p < 0.00001$) than the other LED lights.

The LED lights moreover significantly differ one from the other in interest ($p < 0.00001$) being the LED-A (3080K) more interesting than LED-B (3890K), in temperature ($p < 0.00001$) with the LED-A (3080K) warmer than LED-B (3890K), and in violence ($p < 0.044$) with the LED-B (3890K) more violent than LED-A (3080K).

As before, results relative to the halogen source are in agreement with the common consideration of appearing warmer ($p < 0.00001$), weaker ($p < 0.00001$), and softer ($p < 0.00001$). On the other side the interesting ($p < 0.00001$) appearance of the LED light may be justified in this context where young people are visiting a science exposition of their works, and therefore feel rather excited and inclined to arousing lights. Worth of note the halogen light is only considered more desirable than the LED-B (p < 0.001), and the LED-B appears significantly less interesting than the halogen (p < 0.00001), but cooler ((p < 0.00001) and more violent (p < 0.044) than the LED-A.

3.2. *Factorial Analysis*

A more synthetic view of the results is given by a factorial analysis, which has been performed on the row data. The principal component analysis, with Varimax rotation and Kaiser normalisation, was carried out on the raw data, and the resulting factor loadings (cumulative variance = 73. 3) are shown in Table 2.

scales	C1	C2	C3
active-	-,658	-,402	-,306
boring-	-,049	,878	,208
slow-	,595	,518	,102
weak-	,573	,649	-,143
tense-	-,745	-,108	,280
agitated-	-,652	-,436	,325
warm-	,853	,014	,037
desirable-	-,103	,108	,920
brilliant-	-,410	-,749	,043
soft-	,769	,308	-,200

Tab. 2. The factor loadings of the three principal components of the factorial analysis.

The three factors, shown in Table 3, can be interpreted as: 1- “arousal”; 2- “vivacity”; 3- “evaluation” based on the semantic scales which characterise each factor.

Factor 1 - Arousal		Factor 2 - Vivacity		Factor 3 - Evaluation	
Cold	**Warm**				
Violent	**Soft**				
Tense	**Relaxed**				
Active	**Passive**				
Agitated	**Calm**				
Speedy	**Slow**	*Speedy*	***Slow***		
		Interesting	**Boring**		
		Brilliant	**Dull**		
Strong	***Weak***	Strong	**Weak**		
				Desirable	**Undesirable**

Tab. 3. The semantic scale characterising the three factors.

The factorial structure seems quite coherent and well-fitting the characteristics of the lights as emerged in the previous analysis of variance. An arousal factor is quite common in this kind of research, with the peculiarity of including together the Osgood’s [3,4] activity and potency factors which often are separate. Moreover this factor includes semantic scales related to both the subjective psychological effects (relaxed – tense; calm – agitated; passive – active; slow – speedy) and the qualities attributed to the lights (cold – warm; violent – peaceful).

The vivacity factor includes only scales which deal with the qualities of the lights (strong – weak; brilliant – dull; interesting – boring).

The evaluation factor, which concerns the positivity of the light, is saturated by one scale only (desirable – undesirable) which again is related to the quality of the light.

An analysis of variance on original data weighted by the factorial coefficients has been performed to see how participants judged each illumination on the basis of the criteria expressed by the three factors, and the results are plotted in Figure 7.

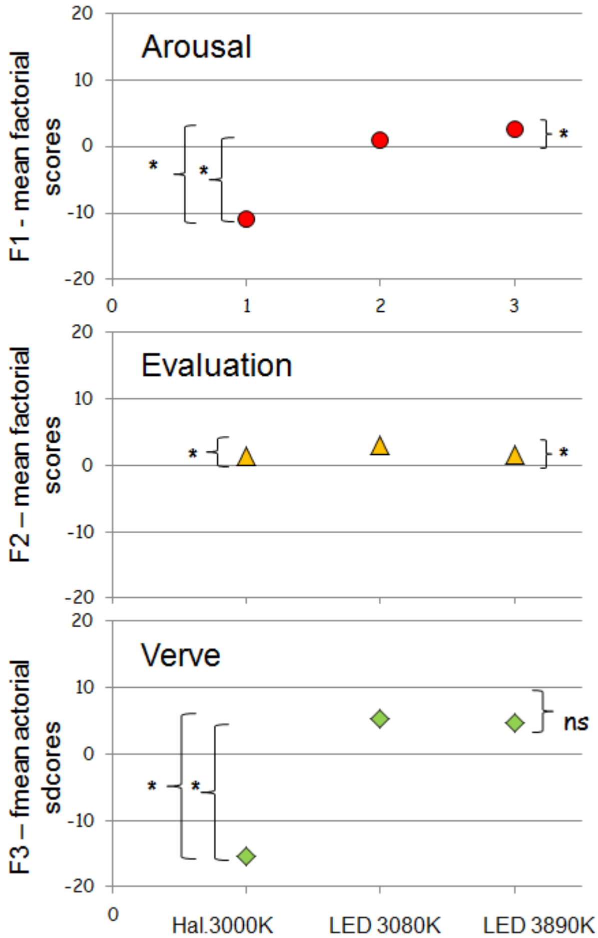

Fig. 7. Factorial scores relative to each factor plotted as a function of the rooms’ illumination.

 DOI: 10.23738/CCSJ.110109

All three illuminations appear significantly different one from the other when judged on the basis of factor 1, that is their arousal power evaluated by participants is different ($p < 0.00001$ in all the three cases); moreover the halogen lamp receives much lower evaluations in absolute value than the other two LED lights. When the lights are evaluated on the basis of factor 2 the halogen light appears connoted significantly less vivid than the LED-A ($p < 0.00001$) but not the LED-B light ($p < 0.44$), and the absolute values of the three evaluations are very close.

Lastly on the basis of factor 3 the halogen light is significantly different from both the LED-A ($p < 0.0023$) and the LED-B ($p < 0.00001$), with its absolute value much lower, while the LED-A and LED-B do not significantly differ, in agreement with the ANOVA results.

4. Conclusions

Noteworthy is that the students are for the first time performing the task requested by the experiment, nevertheless they show great discriminative ability, and also a great consistency. In fact, the dispersion of the results is quite low (in the displayed diagrams confidence intervals are most often smaller than the size of the symbols), thus favoring a good statistical significance. The results demonstrate a clear ability of participants who are able: 1) to recognize and evaluate different personal, psychological reactions to lights; 2) to estimate different qualitative characteristics of the light sources.

The research aimed to highlight how young naive people perceive, discriminate, and judge indoor illuminations produced by different light sources. The attention was focused on the halogen and LED sources, because of the large difference in their spectral power distribution, and the widespread impression that the incandescent sources like the halogen ones are presently preferred by most people.

The first result that emerges is that the three lights are well distinguishable, especially the first vs the other two. Despite both the halogen and the LED-A sources have an almost indistinguishable colour temperature (CCT 3000K-3080K), the two illuminations are always significantly discriminated on all semantic scales, with consideraby different absolute values. Obviously, the same discrimination also takes place between the first and the third illumination, justified by the fact that the sources differ both in type and in the corresponding colour temperature, although not by much (CCT 3000K vs 3890K). The second and the third lighting are not confused, even if the sources are of the same type (LED) and of different, although small, correlated colour temperature (CCT 3080K vs. 3890K): the discrimination, however, occurs only on some semantic scales: interesting-boring, warm-cold, violent-soft. This result challenges the relevance of the CCT in connoting the relevant characteristics of a light source as some subjective characteristics seem to be quite independent from CCT. Some significant quality of the light described by the spectral power distribution (SPD) is probably lost when the CCT is considered.

This research has not investigated the colour rendering properties of the light sources. Nevertheless, the concept of colour rendering was presented and the CRI (colour rendering index, CIE 13.3: 1995) of each source was analysed in the introductory step of the experiment. Moreover, participants were shown three Mondrian (one per room) with the same colours but in a different spatially organized way (always random, anyway) in order to compare the possible colour differences caused by different sources, even if unconsciously.

These overall results agree quite well with the general impression that people have without scientific investigations, and the advantage of the experimentation is to supply a scientific confirmation the current conceptions, and to highlight unexpected aspects. In our case the desirability appears to be low for the light that gives calm, and high for that exciting: the hypothesis is that the situation makes desirable a light with characteristics appropriate to the circumstances. In particular, students who go together to see a show of scientific experiments, perhaps having presented their well accepted works, are not in a state of tranquillity, but rather activated, and therefore prefer an arousing lighting like that produced by LEDs, especially if in those moments they are sensation seeking. It is very likely that in other circumstances the desirability goes calming lights. To be verified.

Conflict of interest declaration

The authors disclose any actual or potential conflicts of interest including financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work. The authors state that financial/personal interest have not affected their objectivity. The authors state explicitly that potential conflicts don't exist.

Funding source declaration

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Short biography

Pietro Fiorentin is associated professor of “Electrical Measurements” and “Light Engineering and Photometry” at the University of Padova. He is responsible of the Photometric Laboratory dealing with external and internal lighting, with particular care to the colour rendering. He studies also the effect of artificial lighting on the night sky luminance, phenomenon known as “light pollution”.

Osvaldo da Pos is Senior Scholar at the University of Padua. Graduated in Biology, taught Physiological Psychology, General Psychology, Psychology of Perception (for the degree in Psychology), and at the Psychology Doctorate Course. Co-founder of the Interdepartmental Centre of Colour and Art, former national representative at CIE and AIC. His main research interest is in the field of colour pschology, especially in colour and illumination perception.

Elena Pedrotti was born in 1980. Graduated in electrical engineering in 2005 and PhD in 2010 from the University of Padua. She works as lighting designer by planning of lighting facilities for indoor or outdoor work places and is worked occasionally with the Laboratory of Photometry and Lighting of the Department of Electrical Engineering of the University of Padua.

Ariella Metellini was born near by Treviso (I) in 1945. She got a degree in physics at Padova University in 1970. From 1970 up to 2001 she had a stable position as a teacher of mathematics and phisics in un agronomical school. After retirement, at the end of 2001, she was responsible of the scientific interactive show "Sperimentando" that is now at the 18th edition.

References

CIE 13.3: 1995, ‘Method of measuring and specifying colour rendering properties of light sources (E)’. ISBN: 978 3 900734 57 2

CIE 212:2014, ‘Guidance towards Best Practice in Psychophysical Procedures Used when Measuring Relative Spatial Brightness’. ISBN 978-3-902842-51-0

Davis, R.G. and Ginther D.N. (1990) ‘Correlated color temperature, illuminance level, and the Kruithof Curve’, Journal of the illuminating Engineering Society, 9, 27:38. DOI: 10.1080/00994480.1990.10747937

Farini, A. (2015). Color Rendering of Light Sources. In Sustainable Indoor Lighting (pp. 77-85). Springer, London.

Jin, C., Noguchi, H., Qiu, J., Wang, H., Sun, Y., & Lin, Y. (2015, November). The effect of color light combination on preference for living room. In Solid State Lighting (SSLCHINA), 2015 12th China International Forum on (pp. 139-142). IEEE.

Sansoni, P., Mercatelli, L., & Farini, A. (2015). Sustainable indoor lighting. London: Springer.

Osgood, C.E., Suci, G., Tannenbaum, P. (1957). The measurement of meaning. Urbana: IL: University of Illinois Press.

Snider, J.G., Osgood, C.E. (1969) Semantic Differential Technique: A Sourcebook. Chicago: Aldine.

Tantanatewin, W., & Inkarojrit, V. (2016). Effects of color and lighting on retail impression and identity. Journal of Environmental Psychology, 46, 197-205.

Thornton WA (1974) A validation of the color-preference index. Journal of the Illumination Engineering Society 4:48–52

Yildirim, K., Hidayetoglu, M. L., & Capanoglu, A. (2011). Effects of interior colors on mood and preference: comparisons of two living rooms. Perceptual and Motor Skills, 112(2), 1-16