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A PILOT STUDY ASSESSING SHORT-TERM CHROMATIC ADAPTATION PREFERENCES FOR CORRELATED COLOUR TEMPERATURE IN INDIA

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ABSTRACT

This small-scale pilot study investigates peoples' short-term chromatic adaptation preferences for correlated colour temperature (CCT) within the cultural context of India. White tone CCT preferences were investigated using a spectrally tuneable LED lighting system. A mock-up room was built and illuminated with two LED luminaires. Each LED luminaire has 216 clusters and each cluster comprising three LED with CCT equal respectively to 3000 K, 4000 K and 6500 K (total 648 LEDs per luminaire). User preference studies in a generic environment were conducted with 50 Indian subjects, where each subject performed generic everyday activities, such as reading, watching TV, eating and relaxing, while being totally immersed in three different scenes of 3000 K, 4000 K and 6500 K. The study shows 6500 K is the least preferred CCT, and 4000 K is preferred for task-oriented activities such as reading and eating. Furthermore, subjects are unable to differentiate between 3000 K and 4000 K while performing non-task-oriented activities such as relaxing and watching TV.

Keywords: correlated colour temperature (CCT), LED lighting, short-term adaptation, culture

1. INTRODUCTION

This small-scale pilot study aims to provide guidance for improved user acceptance of LED products by researching peoples' short-term chromatic adaptation preferences for the correlated colour temperature of illumination. CCT is defined as the temperature of the Planck's radiator having the chromaticity nearest the chromaticity associated with the spectral power distribution (SPD) of the light source in a specific colour space, and describes the appearance of illumination along a reddish-yellowish-white to bluish-white dimension [1]. Chromatic adaptation is defined as the human visual system's ability to adjust to changes in illumination to preserve the colour appearance of objects, and is responsible for the stable appearance of object colours against the spectral changes of the illuminant [2]. Short-term chromatic adaptation results from an exposure of 15 minutes or less to a chromatic light, with the adaptation effect decaying within seconds or minutes [3]. Research [4] reveals that chromatic adaptation at constant luminance is 90 % complete after approximately 60 seconds of exposure. The present study focuses on the perceived white tone CCT preferences of the illumination itself for performing generic everyday activities: reading, watching TV, eating and relaxing, instead of the colour appearances of objects under the illumination.

The objective of this study is to assess whether culture plays a role in people's short-term chromatic adaptation preferences for CCT. Cross-culture studies [5–7] indicate the need for light sources that have the ability to dynamically tune their colour quality of illumination as they can facilitate well-being of people, both within a single cultural group and within different cultural groups. As one of the

determinants for the colour quality of illumination, the CCT of light sources plays an imperative role in addressing both psychological and physiological functions [8]. Short-term chromatic adaptation preferences for CCT are emphasised in this study because research [9–11] reveals that once people are fully adapted to the illumination conditions, CCT in the range (2500–6500) K has little effect on people's subjective preferences of illumination.

Current developments in LED-based lighting systems have enabled the CCTs of illumination to be adapted to suit people's different needs [12]. India is poised to emerge as the largest market for LED-based lighting systems with its government-led schemes for replacing all inefficient lamps by LEDs [13]. Its state-run nodal agency Energy Efficient Service Ltd (EESL) responsible for conversion from older technology (compact fluorescent or incandescent) to LED is committed to its target of selling 770 million LED lamps by 2018. The EESL's distribution scheme titled Unnat Jyoti by Affordable Lamps for All (UJALA) played an important role in lowering the retail price of 9 watt LED lamps to as low as US $1.00 per unit to encourage consumers to opt for these energy efficient lamps. Considering the fact that the UJALA scheme doles out LED lamps with a static CCT of 6500 K, the study uses India as the cross-cultural test-bed for sampling population to determine, whether 6500 K is the actual preference of Indian population. The present study, however, limits its scope to 3000 K, 4000 K and 6500 K, as these are the three most readily available CCTs at the Indian market.

2. METHODS

The overall research strategy follows a repeated-measures experimental study design, with a cross-sectional design format where the sample population is tested only once to gather and compare responses. A total of 50 subjects in smaller groups of three or four were presented with an experimental set-up and expected to complete a questionnaire. While 50 subjects is too small a sample size to be representative of the entire Indian population, this pilot study first aims to understand its impact by conducting it with a population of a singular Indian city, before conducting similar studies in other cities. The experiment was conducted in the south Indian city of Hyderabad, with subjects sampled from this city.

Literature [11] reveals that specification of CCT alone does not pinpoint the precise SPD used in a study as many different SPDs can have the same CCT. Therefore, colour rendering index (CRI) was also considered along with CCT for specifying the test luminaires in this study, as there are only two widely used metrics in India for differentiating the colour quality of illumination. CRI is defined as the effect of a light source on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference light source, and is determined by the SPDs of the respective light sources [14]. The physical set-up consisted of an experimental room illuminated by a tuneable LED lighting system generating three scenes of 3000 K, 4000 K and 6500 K at a CRI of 80 and average illuminance of 300 lx at the table-top level as depicted in Fig. 1. The CCT and CRI ratings are based on the manufacturers' data available for the LED lighting system. The entire experiment lasted for approximately 9 hours spanning over two days with each group being allotted approximately 40 minutes for the experiment.

2.1. Physical Set-Up

The experiment was conducted in a confined room without a window as external source of light inside the office of *Thea Light Works* in Hyderabad. The dimension of the room was 3.0×2.9 ×3.0 m (l × b × h) where the room was being illuminated by two LED luminaires (L) installed in the grid ceiling as per the layout depicted in Fig. 2. The room

Fig.1. Experimental room with tuneable LED lighting system generating three scenes of CCTs 3000 K, 4000 K and 6500 K respectively at an average constant illuminance of 300 lx at the table-top

Table 1. Surfaces Reflectance of the Room

Room surface	Material	Colour	Reflectance
Ceiling	Acoustic tile	Matt black	0.05
Wall 1	Plaster	Painter's grey	0.28
Walls 2, 3	Chip board	Painter's white	0.82
Floor	Local stone	Matt black	0.05
Table	Wooden	Pine	0.45
Shelf	Wooden	Matt white	0.85
Chairs (4 Nos.)	Plastic	White/Black/Blue	0.85/0.10/0.50
LCD screen (off)	Liquid crystal	Black	0.12

temperature was maintained at 24 °C with the help of a wall-mounted air-conditioning unit. The room was equipped and furnished to provide a space that allows subjects to read, watch TV, eat and relax. A rectangular light pine-coloured table was placed adjoining the wall opposite the entrance door along with four office chairs. The table height was 0.7 m. A wall-mounted flat 24" LCD TV screen was also set on the adjoining wall, directly above the table. The monitor's settings (brightness, colour temperature, gamma, saturation, hue and grain) were maintained constant throughout the experiment. There was also a bookshelf integrated with the wall adjacent to the door for storing all the experiment-related materials such as coloured magazines and eatables. During the experiment, printed questionnaires and pens were placed on the table. The room surfaces reflectance are presented in Table 1.

2.2. Luminaires

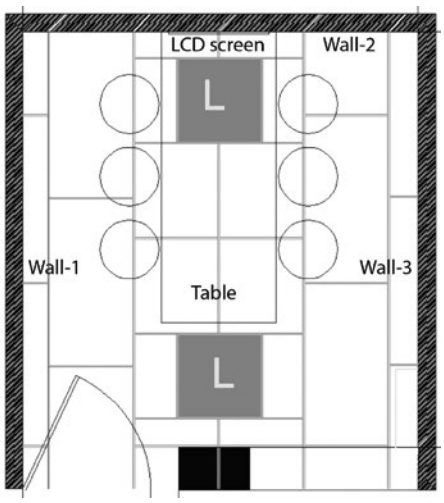

Fig.2. Experimental room layout where "L" represents the LED panel integrated within the grid ceiling

Two ceiling-recessed LED luminaires with dimensions 598 mm × 598 mm × 86 mm each, were custom-designed to illuminate the room. The luminaires and its compatible control system were built with the help of an LED luminaire manufacturer, using four main components:

- LED Panels – 3-channel Panels fitted with Edison LEDs [PLCC2835 0.2W LC CRI80];
- Driver – Osram Optotronic Constant Voltage DALI Dimmable Driver [OTi DALI75/220–240/24 1–4 CH];
- Controller – Philips LightMaster Modular 4-Channel Controller [PDLPC416FR-KNX];
- IR Receiver – Busch-Jaeger Triton 3/6-fach MF/IR [320/30–24G].

Each luminaire comprised six LED panels; each LED panel comprised 36 LED clusters; each LED cluster comprised three different LED types of CCTs 3000 K, 4000 K and 6500 K with a constant 80 CRI as per the LED manufacturer's data i.e. 648 LEDs in total as depicted in Fig. 3. A plexiglas diffuser, which blended the light to provide homogeneous luminance of the luminaire opening, covered the LED panels. The variations in CCT and CRI occurring due to inter-reflections within the luminaire and diffusion through the plexiglas were not taken into consideration for this study. Three drivers drove each luminaire where LEDs of identical CCT were on a single channel thereby enabling each CCT in the luminaire to be controlled by one driver. The two luminaires and its six drivers were connected to a controller, thus making it possible to control the CCT and illuminance of the luminaires with an IR receiver.

2.3. Sampling Population

Table 2. Demographic Analysis of the 50 Subjects from Hyderabad

Age Group	**16–24**	**25–34**	**35–44**	**45–54**	**55 & above**
	7	**25**	**8**	**4**	**6**
Monthly Income [INR]	*Below 5,000*	*5,000–24,000*	*25,000–49,000*	*50,000–74,000*	*75,000 & above*
	02	21	11	7	9
Religion	*Christian*	*Hindu*	*Muslim*	*Jain*	*Sikh*
	4	42	2	1	1
Travel – Inside India	*Bangalore*	*Chennai*	*Delhi*	*Kolkata*	*Mumbai*
	33	27	30	20	36
Travel – Outside India	0 visits	1 visits	2 visits	3 visits	4 visits
	23	7	4	3	13
Gender	*Male*		*Female*		
	35		15		
Area of Residence	*Urban*		*Suburban*		
	41		9		
Education	*High school or below*		*Graduate or above*		
	11		39		

As the intention of this experiment was to obtain feedback from a wide range of subjects from India with different ages, gender and socio-economic backgrounds, a simple random sampling method was used where a generic invitation applicable to a general population was prepared. Additionally, by ensuring that all participants were selected in a random fashion and given an identical treatment, the influence of any form of individual characteristics was eliminated. The 50 subjects who agreed to participate in the experiments included members of the general public as well as staff from the commercial building premises where the experiment was conducted. Table 2 lists a brief demographic analysis of the 50 subjects. Majority of the subjects are between the age group of 25–34 (50 %), have a monthly income between INR 5,000–24,000 (42 %), follow Hinduism (84 %), have visited Mumbai (72 %) in comparison to all the other major cities in India, have travelled outside India (54 %), live in urban areas [82 %], and have completed graduation (78 %).

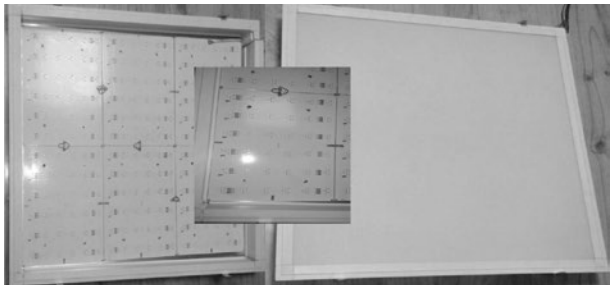

Fig.3. Ceiling-recessed luminaire with six LED panels covered by a Plexiglas diffuser for homogenous luminance

2.4. Experimental Procedure

A questionnaire was designed, which first asked the subjects to visually experience the three scenes with 3000 K, 4000 K and 6500 K by being completely immersed in them, before identifying any variability in the scenes. The scenes with the different CCTs were presented to the subjects in various different orders in order to counterbalance any carry-over or ordering effects by slowly interchanging them a couple of times. As the intention was to obtain short-term chromatic adaptation preferences, the time allotted to experience each scene was short, approximately 90 seconds, to ensure that subjects' eyes are not fully adapted to each CCT. In case of any perceptible variability in the three scenes, the subjects were asked to name this difference. Subjects were then asked which of these CCTs were they previously aware of in terms of their availability in the local market: '1 – Not aware' and '2 –

Fig.4. Subjects performing the different activities of reading, watching TV, eating and relaxing while being completely immersed in the three different CCT

Aware.' Subjects were finally asked to list areas, buildings or localities, which according to them were the most suitable applications for these CCTs.

Subjects were then asked to perform four activities of reading, watching TV, eating and relaxing in the three scenes, and rate their preference of each CCT for performing these activities under the categories: '1 – Not Appropriate', '2 – Somewhat Appropriate' and '3 – Appropriate'. The time allotted for each activity was approximately ten minutes with each of the three CCTs being interchanged after approximately 90 seconds. Subjects were also given the freedom to rate their preferences from the questionnaire at any time during these ten minutes allotted for each activity. For reading, subjects were provided with magazines. Magazines were the preferred reading material considering their variety in content presentation through font sizes, coloured pictures, etc. For watching TV, a video clip from the national geography channel was played for the subjects. For eating, subjects were offered fruits and snacks. For relaxing, subjects had the free will to relax in whichever manner that suits their comfort. The subjects performing various activities in the experimental room are presented in Fig. 4.

3. RESULTS AND ANALYSIS

Statistical Package for Social Sciences (SPSS) for Windows was used to perform nonparametric tests to calculate the percentages of responses, the mean ranks, p-values and significance levels. Cochran's Q test and percentages of responses were used for calculating the statistical significance of tests that involved binary response variables. Friedman's test and mean ranks were used for all other tests, which involved more than two response variables. Wilcoxon's test was used for a pairwise comparison of the three CCTs. The qualitative data was coded by the method of systematic observation, where careful observation of one or more specific behaviours in a particular setting was recorded.

All 50 subjects perceived a difference in the three scenes; 30 related this difference to colour and 20 related it to brightness. Majority (90 %) of the 20 subjects who related the perceived difference in the scenes to brightness were from the income groups of INR 24,000 and below or an education level of high school and below. Tables 3 and 4 list the descriptive and inferential statistics respectively obtained from the sample population. Table 5 lists the pairwise comparisons of the three CCTs to assess which CCTs are different from each other. Sub-

Table 3. Summary of Means, Standard Deviations and Minimum-Maximum Range for the Three CCTs

Activity	3000 K			4000 K			6500 K		
	M	***SD***	***Min-Max***	***M***	***SD***	***Min-Max***	***M***	***SD***	***Min-Max***
Awareness	1.18	0.388	1–2	1.22	0.418	1–2	1.26	0.443	1–2
Reading	1.80	0.756	1–3	2.48	0.677	1–3	2.22	0.815	1–3
Watching TV	2.26	0.828	1–3	2.24	0.657	1–3	1.78	0.815	1–3
Eating	2.16	0.817	1–3	2.34	0.745	1–3	1.86	0.833	1–3
Relaxing	2.44	0.861	1–3	1.84	0.734	1–3	1.66	0.848	1–3

Table 4. Percentages of Responses and Mean Ranks for the Three CCT

Activity	3000 K	4000 K	6500 K	P	Cochran's Q [df=2]
	Aware % [Not Aware %]				
Awareness	82 % [18 %]	78 % [22 %]	74 % [26 %]	0.050	6.00
	Mean Ranks				X^2 *[df=2]*
Reading	1.45	2.47	2.08	<0.001	51.94
Watching TV	2.25	2.22	1.53	<0.001	36.87
Eating	2.06	2.33	1.61	<0.001	36.75
Relaxing	2.25	2.22	1.53	<0.001	36.87

jects were more aware about the availability of 3000 K in the market as it received the highest percentage of favourable response. Subjects preferred 4000 K for reading and eating as it received the highest mean rank. Although subjects did not perceive any difference between 3000 K and 4000 K while watching TV and relaxing as $p > 0.05$ for their respective pairwise comparisons, both CCTs received similarly high mean ranks for these two activities. Table 6 lists the subjects' preferences of these CCTs for possible real-life applications in different areas, buildings or localities. All 50 subjects have travelled to at least one other city in India, while 27 of them have travelled outside India. The sample size was not large enough to draw any other relationship of statistical significance with respect to age, gender or socio-economic backgrounds.

While majority of the subjects are aware about the availability of the three different CCTs for LED luminaires in India, 40 % of the subjects were not able to relate this difference to the colour quality of illumination. For task-oriented activities such as reading and eating, 4000 K is considered the most appropriate. Maximum numbers of subjects associate 4000 K for task-oriented applications such as classrooms, offices, workspaces and kitchens. However, 3000 K is considered the least appropriate for reading, and 6500 K is considered the least appropriate for eating. Maximum numbers of subjects associate 3000 K for applications such as restaurants, bars or hotels; and 6500 K with applications such as hospitals and supermarkets as shown in the application survey. For non-task-oriented activities such as watching TV and relaxing both 3000 K and 4000 K are considered almost equally more appropriate than 6500 K. Overall, the study reveals that 4000 K and 6500 K are the most and least preferred CCTs respectively.

4. DISCUSSIONS

Literature reviews of previous cross-cultural studies on the preference of the colour appearance of objects under LED illumination of different CCT reveal mixed results. A study [6] on Chinese and American observers living in the US reports that: for very familiar objects (fruits and vegetables) and paintings, no cultural differences were found; for less familiar or unfamiliar paintings, cultural differences were found depending on the content; American observers exhibited noticeably wider differences. A similar study [7] on Chinese and European observers living in Germany reports that: Chinese women prefer warm white CCT (2700–3500) K for

Table 5. Pairwise Comparisons of Preferences in the Three CCTs

Activity	(3000–4000) K		(3000–6500) K		(4000–6500) K	
	Z	***p***	***Z***	***p***	***Z***	***p***
Reading	–5.831	<0.001	–4.583	<0.001	–3.606	<0.001
Watching TV	–0.277	0.782	–4.899	<0.001	–4.796	<0.001
Eating	–3.000	0.003	–3.873	<0.001	–4.899	<0.001
Relaxing	–0.277	0.782	–4.899	<0.001	–4.796	<0.001

Table 6. CCT Preferences for Different Applications

	Area/Building/Locality											
	Classroom	Garden	Hospital	Industrial Workshop/ Warehouse	Kitchen	Office/ Workspace	Place of Worship	Playground/ Stadium	Restaurant/ Bar/Hotel	Retail Store/ Showroom	Street/Path-way	Supermarket
3000K	4	23	5	7	9	5	20	6	33	18	20	6
4000K	26	3	19	14	19	20	6	6	6	12	3	12
6500K	11	9	25	14	11	14	7	18	5	13	11	21

reddish objects in contrast to Chinese men and Europeans; a general preference of 4000 K (in certain cases up to 5000 K) could be observed for the bluish and colourful combination than for the reddish objects; Europeans do not prefer warm white (2700–3500) K for bluish and colourful objects. Four studies that have independently experimented with interchangeable CCT in office lighting environments for workers in Asia [8,15,16] and Europe [12] report a similar result that 4000 K is the most comfortable and most preferred CCT than 3000 K and 6500 K. A study [17] on LED office lighting that experimented with Africans, Asians and Europeans living in Finland reports that Europeans prefer a lit environment under CCT 4000 K, while Africans and Asians preference between 4000 K and 5000 K depends upon illuminance levels.

Relating the results of these previous cross-cultural studies with this study has led to the following observations:

- Educational and economic backgrounds might play a role in relating the perceived chromatic differences in illumination to colour quality or more precisely to CCT. Majority of the subjects who related the perceived differences between the three scenes to brightness instead of colour were either from a lower income group or lower educational background.
- Travelling and exposure to different cultures might play a role in influencing people's preferences and associations with a particular CCT. The preference of 4000 K for eating, while an association of 3000 K with eating places like restaurants and hotels can be accounted to the subjects' travel experiences and exposure to fine dining places illuminated with warmer CCTs.
- A CCT of 4000 K seems to be universally acceptable across most cultures for familiar office-oriented activities. The preference of 4000 K for a task-oriented activity like reading supports to a certain extent the results of the previous studies [8,12,15–17] on office lighting. This may also explain why a CCT of 3000K is considered unsuitable for an office-oriented activity like reading as people relate it more to an environment conducive for non-task-oriented activities like watching TV or relaxing.
- Differences of up to 1000 K at the reddish-yellowish-white dimension of the CCT are not noticeable while performing non-task-oriented activities. The subjects' inability to report any difference between 3000 K and 4000 K was only while performing the non-task-oriented activities like relaxing or watching TV.
- While the present study did not consider the impact of different skin tones on CCT preferences, it certainly is a case in point for future research considering the various differences in skin tones within the Indian population. Research reveals [18] that people are very sensitive to CCT preferences when their skin is used as a target of observation.

5. CONCLUSIONS

Two broad conclusions can be drawn from the results of this study. First, the people of Hyderabad have a general preference for 4000K while performing most activities and tasks. Second, the government-led UJALA scheme for distributing LED lamps at subsidized rates needs to establish people's preferences for CCT before implementation. The fact that people of Hyderabad do not have much of a preference for 6500 K provides sufficient evidence to disagree with the UJALA scheme. The practical applications of this study include areas where the choice of CCT has an impact on the immediate entry

to buildings is important, such as in retail and hospitality lighting. The results of this study can also be practically used by the UJALA scheme to reassess their decision of doling out 6500 K lamps. The answer to the overarching question whether culture plays any significant role in people's preferences for CCT requires further investigation and validation with similar experiments conducted across different cities in India using larger samples sizes.

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