

## **THE EFFECT OF LED LIGHTING ON PERFORMANCE, APPEARANCE AND SENSATIONS**

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### PURPOSE

Since Kruithof [1] published a paper on general illumination, it has been accepted that users would find "pleasing" high correlated colour temperature (CCT) illumination at high illuminance and low CCT illumination at low illuminance. Here, we question the origin of the pleasing sensation. We have used LED lighting to re-visit Kruithof's rule and precisely to test the combined effect of CCT and illuminance on visual performance, colour appearance and subjective feelings.

### METHODS

Several illuminations were obtained using adjustable LED clusters. Blue, cyan, green, amber, orange, red, one-phosphor cool light and/or two-phosphor warm white LEDs allowed us to produce all combinations of illuminance  $E = 150 \text{ lx}$ ,  $300 \text{ lx}$ ,  $600 \text{ lx}$  and correlated colour temperature  $T_{cp} = 2700 \text{ K}$ ,  $4000 \text{ K}$ ,  $6500 \text{ K}$ . Each illumination was obtained using as many LED varieties as necessary to obtain the target illumination with the highest available Colour Rendering Index ( $\text{CRI} > 90$ ).

Visual performance was tested in terms of acuity, contrast threshold, reading.

Colour appearance was tested in terms of colour preference, binary hue selection, landscape reminiscence.

Subjective scales were proposed to characterize the illumination: Glaring – Non glaring, Dark – Bright, Cold – Warm, Artificial colour rendering – Natural colour rendering, Crepuscular – Clear, Dull – Cheerful, Tiring – Relaxing, Uncomfortable – Comfortable, Unpleasant – Pleasant.

Every CCT and illuminance combination was appraised by 20 young observers.

### RESULTS

We performed a multivariate ANOVA on the results with three factors: illuminance, CCT and observers.

#### Performance

Results show an effect of illuminance on low and high contrast acuity and an effect of CCT on high contrast acuity. No effect of illuminance or of acuity was found on visual performance which might be explained by the fact that visual performance is conducted by luminance contrast mainly.

#### Subjective feelings

Almost all subjective scales are modified by the CCT. Results indicate an increase of comfort, pleasantness and impression of relaxation, when the CCT decreases, but no effect of illuminance. Results show that brightness, as well as other quantities dealing with the



amount of perceived light such as glare or clarity significantly increases with illuminance as well as with CCT at constant luminance.

#### Colour appearance

With respect to the distribution of hues along the colour circle, as CCT arises, binary hues depart from the blue sample and converge toward the green sample. The shift of binary hues reveals that chromatic adaptation is incomplete.

#### DISCUSSION AND CONCLUSION

Whereas the performance tasks yield results which depend on luminance and only slightly on CCT, observers significantly reported that high CCT illuminations look brighter than low CCT illuminations. We propose to establish a parallel between our results on the one hand and the recently discovered melanopsin photopigment that is included within the cellular body and dendrites of a subset of ganglion cells (ipRGCs) of rodents and primates [2] on the other hand. The stimulus that elicits the response of melanopsin is proportional to the convolution of the spectral power distribution of the LED illumination and the action spectrum of ipRGCs.

Whenever ipRGCs absorb light, it induces a sustained pupil constriction. We checked on a control observer that his pupil constricts when the illuminance increases as well as when the CCT increases. Thus, because the brightness increases even though the amount of light impinging on the retina decreases, a possible indirect mechanism might be operating: the CCT increases, so the melanopsin stimulus increases, so the pupil constricts, then, although less light reaches the retina, the observer "feels" that the illumination is brighter.

Finally, we observe that visual performance probably cannot predict subjective impressions aroused from lighting.

Kruithof, A.A. Tubular Luminescence Lamps for General Illumination, Philips Technical Review, 1941, 6, 65-96.

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Keywords : LED, performance, appearance, melanopsin