Effects on School Children Learning with Lighting Color Temperature

The following Seesmart® Case Study contains portions from an original study article, “A comparison of traditional and high colour temperature lighting on the near acuity of elementary school children” (Lighting Res. Technol. 38,1 (2006) pp. 41_52. Received 15 November 2004; revised 10 May 2005; accepted 10 May 2005). Photographs and charts were added to this Case Study by Seesmart® to illustrate key terms and ideas.

The study tested and demonstrated the improvements in visual acuity in students when switching from traditional, relatively low, Color Correlated Temperature (CCT) lighting to a higher CCT lighting product. The findings of this study are important when considering lighting for an environment that involves reading, writing, and environmental interaction.

Seesmart® offers a broad range of LED solutions to accommodate the needs of every customer. Our products vary in size, wattage and color, enabling custom solutions for any application. Contact Seesmart® with any questions.

Overview
Past studies have shown that varying the ambient light spectrum of essentially white light but at fixed photopic levels affects the visual acuity of adults of all ages. In this study those results including the vision and energy savings implications are extended to young children.

STUDY SUMMARY
A comparison of traditional and high color temperature lighting on the near acuity of elementary school children

COMPARISON STUDY
- Traditional Standard School CCT 3600K “Warm White” Lamps
- Higher CCT 5500K “Day White” Lamps

STUDY TEST RESULTS
- 90% of Students Tested Yielded Better Visual Acuity with the Higher CCT Lamps
- Average Pupil Size Significantly Smaller with Higher CCT Lamps (thus improving visual optical quality)

RECOMMENDED LED PRODUCTS
- Seesmart® SKU #200009 LED T8 Day White Clear Lens Tube Lights
- Seesmart® SKU #200005 LED T8 Day White Frosted Lens Tube Lights

RESULTS
Based on visual acuity as a criterion for light level high CCT 5500K Lamps, such as Seesmart® LED T8 Tubes in Day White, provide a highly cost effective means for achieving improved vision and major energy savings.
Near visual acuity (obtained by utilizing Bailey-Lovie letter charts adjusted for the typical reading condition of 400 mm distance) of 27 children aged 10-11 years old was measured by a licensed optometrist under ceiling lighting provided by two different but readily available fluorescent lamps. The measurements were obtained in a room on the school premises outfitted with specially designed lensed luminaries that simultaneously housed both lamp types whose light levels were separately controllable by a wall mounted switch/control.

One lamp type was the traditional standard school fluorescent lamp of measured correlated color temperature (CCT) 3600 K while the other lamp was of higher color temperature with a measured CCT of 5500 K. The luminaries were specifically designed to provide equal luminance distributions for each lamp type.

Acuities were measured under three lighting conditions, either both lamp types providing equal task luminance or a condition where the task luminance of the 5500K lamp was set to a 50% lower value. The equal luminance conditions had the luminance at the eye of the tested student (in the direction of gaze) adjusted to the value 85 cd/m². For the equal lighting condition, the Wilcox on sign test applied to the results showed that visual acuity was significantly better (PB/0.001) under the higher CCT lamp with 24 of the 27 children having better acuity under the higher CCT lamp.

There was one tie score while two scored better under the standard lamp. (Also noted, the tie student and one of reversals did better under the lower luminance condition than either of the other two conditions.)

Paired t-tests comparing the lower luminance condition showed a significant difference for the 5500 K lamps at the two luminance’s, but no significant difference when comparing the 3600 K lamps at the higher luminance value with the 5500 K lamps at the lower luminance. However there was a strong trend for the 5500 K lower luminance condition to provide better acuity with the results showing six ties and 14 out of the remaining 21 having better acuity under the lower luminance condition of the 5500 K lamps.

Pupil sizes of four children under the two different lamp types for the equal luminance condition were also measured based on averaging multiple frames of calibrated video camera images of their eyes. Average pupil size was significantly smaller under the 5500 K lighting as compared to the 3600 K lighting for all these children consistent with prior measurements of adults. This suggests an explanatory mechanism of the results based on the relatively more bluish spectral content of the 5500 K lighting causing comparatively greater pupil constriction and thereby improving visual optical quality. Based on visual acuity as a criterion for light level, these results imply a highly cost effective means for achieving improved vision and major energy savings by employing higher color temperature lamps for school lighting.

**Introduction and Background**

During the 1990s a number of laboratory studies carried out on young adults and set in simulated work environments compared the effects of different light spectra on visual acuity, contrast sensitivity and brightness perception. Those studies found that light with greater blue content ie, higher correlated color temperature (CCT) allowed better visual acuity and
greater brightness perception compared to light of lower CCT, both lighting conditions controlled to be at the same photopic light level. Furthermore the laboratory studies demonstrated that the underlying mechanism for the acuity results was due to the greater effectiveness of bluish spectral content on pupil size variation. The higher CCT lighting yielded comparatively smaller pupils for a given photopic light level thereby confining the object light rays to the more central region of the eye where optical quality is generally better.

Subsequent studies on more than 100 young adults found similar results on both distance and near visual acuity where the spectrum of the surround lighting was varied while either the task lighting was the same as the surround or alternatively designed so that its spectrum remained fixed. At the same illuminance level, surround lighting of higher CCT provided better acuity, consistent with the above laboratory results that claimed pupil size is mainly controlled by the surround lighting and its spectrum. It has also been speculated that the acuity benefits resulting from a spectrally driven pupil would lead to an improvement in reading speed. These previous studies suggest a new principle for lighting applications where higher CCT lighting is substituted for the present choice of lower CCT lighting that is the typical standard for most buildings. This principle allows, at one extreme, to obtain maximum acuity benefits by keeping light levels unchanged or at the other extreme to obtain maximum energy savings by lowering light levels with the higher CCT lighting while maintaining the status quo for acuity. The extension of such a principle to school buildings would also be supported if the visual benefits obtained for adults occurred as well for children. The study reported here was undertaken principally for that reason.

**Testing**

A practicing licensed optometrist (MJM) measured the students’ visual acuity with the charts held in a vertical position and at a testing distance of 400 mm. To maintain this distance during testing, a fixed string placed across the desk was in contact with the bridge of the student’s nose. A separate recording form was provided for each tested student that contained the particular chart letters and the lighting information. The following testing rules were then applied. Each tested student was closely monitored to assure that the test distance was accurate and that s/he was not squinting. The student was firmly encouraged to guess all of the letters. Each measurement for all conditions was started on the top line and finished on the one line for which the student could not correctly identify any of the letters. They were tested on all lines in between. For each row on which the student was tested, each letter that they properly identified was circled on the recording form and added one point to the score.
Pupil Size Measurements
In a separate testing session in the test room, pupil area measurements of four children (three girls, one boy) who did not participate in the acuity study but who were of the same age group were determined under the equal luminance condition for the low CCT and high CCT lightings. The measurements were obtained by analyzing digital images of the portion of the upper face containing the eyes. The images were gathered by a Sony video camera (model 4000) at the rate of 28 frames per second with 10 s of data for each child under each lighting condition. Calibration of the images was determined by placing sensors of known fixed size in the eye position of a manikin’s head placed in the student viewing position. During the data gathering the tested children fixated on the camera that was positioned on the desk at the chart position ie, 40 cm from their forehead. To assure that pupil size had adapted to the different lighting conditions, at least 5 min of adaptation time was allowed before data were taken. The pupil area was calculated from each frame by pixel count. Mean pupil area for each child under each lighting condition was determined by averaging the 70 data values obtained from every other frame over a 5-s data interval. The 5-s interval was arbitrarily chosen from the middle of the 10-s period but was the same selection for all the tested children. In addition to the mean pupil areas the maximum and minimum pupil areas of the continuously fluctuating pupil of each tested child were also determined.

Discussion
The reading of printed matter or of a computer screen is one of the most ubiquitous activities of our society. A tried and true measure of the visual clarity of letters is the measurement of visual acuity, as better visual acuity means that the letters are seen more clearly and sharply. A lighting environment that can provide optimum acuity in an economically efficient manner should therefore be considered as both desirable and advantageous.

The results of this study show that both light level and lighting spectrum affect visual acuity under typical conditions of reading. It is not surprising that light level affects acuity, but there is a general absence of appreciation for the effects of light spectrum. In this study where two different but commercially readily available light spectra were compared for their effects on the near visual acuity of elementary school children, the results showed significant effects of spectrum. At the same light intensity at the eye, visual acuity was significantly better for the high CCT lighting. Furthermore visual acuity was at least equal to (and with a strong trend to be better) than the traditionally installed low CCT lighting when the high CCT lighting level was reduced by 50% compared to the low CCT lighting. These results suggest a highly cost effective strategy for improving elementary school classroom lighting based on replacing the conventional low CCT (3500K) lamps with high CCT lamps (5500K or higher).

The particular strategy varying at one end from maintaining the status quo in visual acuity with maximum savings in lighting energy costs or at the other end maintaining current lighting energy costs but providing a higher degree of visual acuity. The changing of pupil size under the two different spectra offers a credible mechanism for the results obtained here. Such a mechanism is consistent with current views of optical quality of the eye and with previous laboratory spectral acuity studies of both young and elderly adults. These previous laboratory studies investigated the spectral and intensity variation of steady state pupil size of many adult subjects at typical photopic levels and established that pupil size variation closely followed a scotopic-like spectrum. The measured pupil size variations were completely incompatible with standard photopic sensitivity function. Similar conclusions about the spectral dependence of other papillary behavior have recently been found in mice and primates. A smaller pupil improves retinal image quality and visual acuity by eliminating peripheral aberrations and also by increasing the depth of focus for an eye especially with an uncorrected refractive error. At light levels typical of interior environments, this positive effect overcomes any reduction of acuity resulting from the decrease in retinal illuminance associated with a smaller pupil. This conclusion is also supported by data from previous studies.
Case Study

Each of the four children whose pupil size was measured under the two spectra had smaller pupils under the high CCT lighting. Although the pupil sizes of the participating children were not measured during the actual acuity testing, we suggest that if their pupils were measured, the resultant size differences would most likely be consistent with the data of the four children measured. Thus a parsimonious explanation of the spectral acuity effects found here is that these are a consequence of the spectrally induced pupil size changes.

The vertical placement of the eye chart during testing closely simulates the vision conditions of computer reading, especially the accommodation requirement. Because smaller pupils reduce the eyes’ accommodative response it is possible, besides the acuity benefit that a greater degree of visual comfort could be provided by high CCT ambient lighting in the computer environment.

Conclusions
The results presented here show that by changing from the more traditional 3500K lighting to higher color temperature lighting it is possible to provide a higher quality of the visual environment at a reduced lighting energy cost. This double benefit should be a consideration for those concerned with management of elementary school education.

References

Source of Text:

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Sources Cited:

2 Milova A. The influence of light of different spectral composition on the visual performance, CIE Compte Rendu, 17th Session of the CIE. Barcelona; 1971: 84_/85.

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