León 05
CIE Midterm Meeting y
Congreso Internacional de Iluminación

Título del trabajo/
Title of paper

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Presented May 18, 2005

# Children's Near Acuity is Better under High Colour Temperature Lighting.

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## ABSTRACT

During the 1990's a number of studies were carried out in simulated office environments demonstrating that varying the ambient light spectrum of essentially white light at a constant photopic level affects visual acuity of adults of all ages. In this study those results are extended to the measurement of near acuity in young children of ages 10 &11 years.

Bailey-Lovie letter charts specialized for the typical reading condition of 40 cm distance were implemented to determine the near visual acuity of 27 children ages 10&11 years. The measurements were made under lighting provided by 2 different but readily available fluorescent lamps of different CCT values. The acuity evaluations were obtained by a licensed optometrist in a room on the school premises outfitted with specially designed fixtures that simultaneously housed both lamp types. Light levels were separately and continuously controllable by a wall mounted switch/control.

One lamp type was the standard school fluorescent lamp of measured correlated colour temperature (CCT) 3600K while the other lamp had a CCT of measured value of 5500K. The fixtures were designed to provide equal luminance distributions for each lamp type.

Near acuities were measured under 3 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 Wilcoxon sign test applied to the results showed that visual acuity was significantly better ($p<0.001$) under the higher CCT lamp with 24 of the 27 children having better acuity under the higher CCT lamp. There was 1 tie score while 2 scored better under the 3600K lamp. (Also noted, the tie student and one of reversals did better under the lower luminance condition of the 5500K lamp as compared to either of the other 2 conditions.)

Paired t-tests comparing the lower luminance condition showed a significant difference for the 5500K lamps at the 2 luminances, but no significant difference when comparing the 3600K lamps at the higher luminance value with the 5500K lamps at the lower luminance. However there was a strong trend for the 5500K lower luminance condition to provide better acuity with that result showing 6 ties and 14 out of the remaining 21 having better acuity under the lower luminance condition of the 5500K lamps.

Pupil sizes of 4 non-participating children of the same age under the 2 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 5500K lighting as compared to the 3600K lighting for all these children consistent with prior measurements of adults. This suggests an explanatory mechanism of these near acuity results based on the relatively more bluish spectral content of the 5500K 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 or major energy savings by employing higher colour temperature lamps for school lighting.
Keywords: Children, Near Acuity, High Colour Temperature, Lighting Design, Pupil size.

## 1. INTRODUCTION AND BACKGROUND

During the 1990's a number of laboratory studies set in simulated work environments were carried out on young adults and compared the effects of different white-light spectra on visual acuity, contrast sensitivity and brightness perception 1. Those studies found that light with greater blue content, i.e. 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 likely the effect of spectral content on pupil size. The higher CCT lighting yielded comparatively smaller pupils for a given light level 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 2. 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 smaller pupil would lead to an improvement in reading speed 3.

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 spectral correlates obtained for adults occurred as well for children. The study reported here was undertaken principally for that reason.

## 2. METHODS

### 2.1 Participating children

At the outset, letters were sent to the parents of fourth and fifth grade children of a local elementary school inquiring if they had any objections to their child volunteering for a vision test that used different kinds of classroom lighting. There were no objections and a large number volunteered to participate in the study. A subset of 27 children (12 g, 15 b) of ages 10 and 11 from grades 4 and 5 were randomly chosen, with the amount limited by the available spare time of the testing optometrist. Five children wore spectacles and they used them during testing. The participating children were not aware of the purpose of the study and were told that they would be asked to read the smallest letters that they could see

### 2.2 Light fixtures, controls and lamps

Measurements were made in a windowless room of area 3m by 3.7m (10 ft by 12 ft) and height 3.4m (11 ft). Photos of the test room are shown in Figure1. The ceiling was outfitted with

2 equal special 4-lamp light fixtures. Each lighting fixture contained identical pairs of lamps: 2 GE-SP41F32T8SP4 and 2 Verilux-F32T8VLX lamps. The lamp intensities were adjustable via dimming ballasts controlled by a special built dimmer control box located on the room wall. The controls were designed so that either one pair or the other pair of the lamp types in both fixtures was powered together. The control box also contained an external switch allowing the experimenter to switch between the 2 lamp types. The fixtures were manufactured by "MetalOptics" (subsidiary of Acuity Brands Lighting, Atlanta, GA) with specially designed optics, including placement of the lamps within each fixture, so that each pair of lamps provided the same lighting distribution.

The nominal CCT values of the lamps as provided by the manufacturer were 4100K and 6500K respectively. However because of the furnishings and wall colourings in the test room, the measured CCT values on a horizontal surface at the desk level were 3620K and 5500K respectively (Minolta special photometer model xy-DC). The CCT values were also measured in the direction of gaze, i.e. the direction of view of the eyes of the tested student looking at the eye charts, and these had the values 2910K and 4050K respectively.

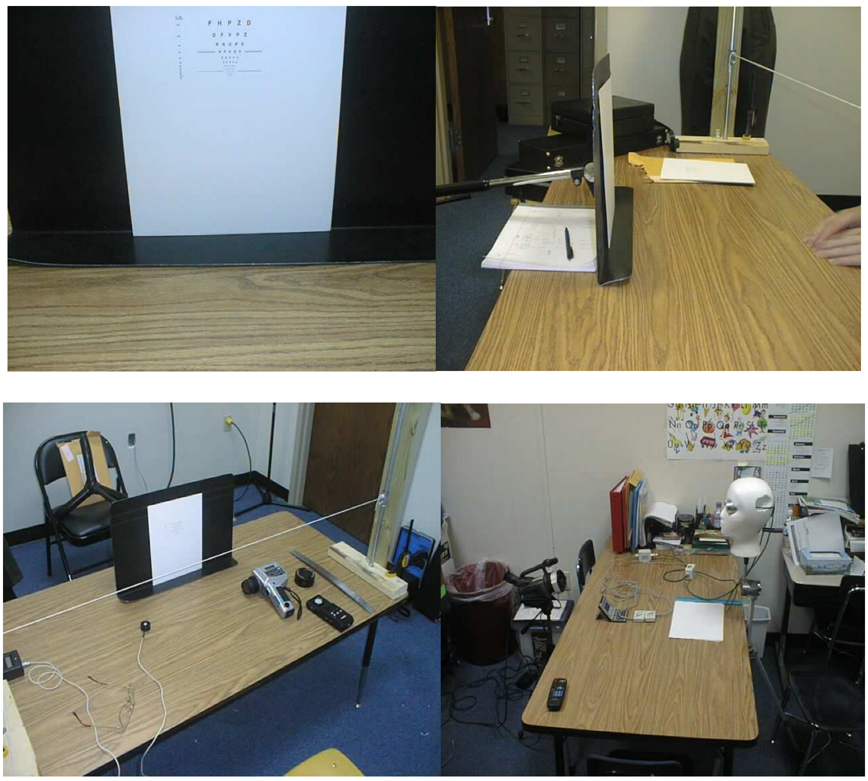

**Figure 1-** Various photos of the test room showing the desk, eye chart in place and in enlargement, the manikin head and video camera. Note that for both the pupil size measurements and related calibration the camera was moved from the position shown and placed on the table with the lens at the eye chart position.

**2.3 Light Levels.**

The illuminance value at desk level from each lamp type was designed to be the same as in the regular classrooms where the horizontal illuminance at desk level was about 500 Lux (50 fc). This was approximately achieved with the test room empty, but in the presence of the room

contents and furnishings the maximum achievable was about 350 Lux, a value nevertheless typical of elementary school lighting conditions.
The test lighting condition for the comparison of the 2 lamp types was first adjusted to achieve equal luminance in the direction of gaze of the student while seated at the desk and reading the eye charts. This assures that there will be an equal intensity of light in the viewing direction for the 2 lamp types. In this case the luminance value was 85 cd/m2, achieved with desktop horizontal illuminances of 350 Lux for the high CCT lamp and 330 Lux for the low CCT lamp. (The luminance of 85 cd/m2 is typical for the screen of a good CRT monitor.) In addition, acuity testing was also carried out for the high CCT lamp with a light level setting adjusted to a 50% lower luminance value (42.5 cd/m2). Thus overall there were 3 different lighting conditions: low CCT, high CCT and high CCT at 50%. Illuminance values were determined with a Minolta photometer model xy-DC and luminance values were determined with a Minolta luminance meter model CS-100 with an aperture set at 1-degree solid angle..

### 2.4 Near Visual Acuity Charts and Scoring.

Near visual acuity was measured using three standard Bailey-Lovie charts 4 reduced in size for a 40 cm viewing distance. The charts were printed with a HP ColorPro GA printer at 1200 dots/inch that enabled good letter resolution down to a Snellen acuity level of 6/3(-0.3 logMAR) 5. The charts contained a logarithmic progression of 12 rows of 5 letters per row with each row 0.1 logMAR units smaller than the row above. The top row had Snellen acuity of 6/38 (0.8 logMAR) and continues to the bottom row of 6/3 (-0.3 logMAR). Performance was scored by giving unit credit for each letter correctly identified beginning with a theoretical 6/600line. As a result, a score of 95 was given for all letters correctly identified up to and including 6/7.5 (0.1 logMAR), a score of 100 up to 6/6 (0.0 logMAR) and a score of 105 for 6/4.8 (-0.1 logMAR).

### 2.5 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 40 cm. To maintain this distance during testing, a fixed string placed across the desk was in contact with the bridge of the students' nose. (see Figure 1.) 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.

1. The subject was closely monitored to assure that the test distance was accurate and that s/he was not squinting.
2. The subject was firmly encouraged to guess at all letters within the range defined in #3 below.
3. Each measurement for all conditions was started on the top line and finished on one line for which the student could identify no letters. They were tested on all lines in between.
4. For each row on which the student was tested, each letter that they properly identified was circled on the recording form and added 1 point to the score.

A Latin Square design was employed for testing so that the order of lighting conditions, acuity charts and combinations thereof were equalized across students. Thus any order effects were neutralized.
The recording form mentioned above identifies the order of the lighting conditions (low CCT, high CCT, high CCT at 50%) and the particular acuity chart (identified by the letters on the top line) to be used for each lighting condition.

An adaptation time of 4 minutes under all of the lighting conditions was allowed before testing would commence during which time the optometrist engaged the students in conversations about various activities such as sports and vacations 6. Testing time was approximately 20 minutes for each student.

### 2.6 Pupil Size Measurements

In a separate testing session in the test room, pupil area measurements of 4 children (3 girls,1 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 seconds 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 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 i.e., 40 cm from their forehead. To assure that pupil size had adapted to the different lighting conditions, at least 5 minutes 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-second data interval. The 5-second interval was arbitrarily chosen from the middle of the 10-second period but was the same selection for all the tested children..

## 3. RESULTS

**Table 1** lists the scores for each of the 27 tested children under the 3 lighting conditions based on the numerical scoring algorithm described above. The values in Table 1 show that for the equal luminance condition 24 out of 27 children had better acuity under the high CCT lighting compared to the low CCT lighting. This is highly statistically significant with a probability of less than 10-5 of a reversal by application of the Wilcoxon sign test. The mean visual acuity was approximately 2.5 letters better with the high CCT lighting (paired t-test, $p<0.000005$).

Comparison of the 2 high CCT lighting conditions shows that the 50% luminance condition had significantly lower visual acuity (paired t-test, $p=0.002$) by approximately 1.5 letters. Thus this group of children was sensitive to a lowering of the light level. Visual acuity with the high CCT lighting at 50 % luminance was approximately 1 letter better than the low CCT lighting at full luminance value but did not quite reach significance (paired t-test, $p=0.056$) showing a strong trend for the 50% high CCT visual acuity to be better than the low CCT lighting at full value.

| Child's Name | H CCT | L CCT | H CCT 50% | Child's Name | H CCT | L CCT | H CCT 50% |
|---|---|---|---|---|---|---|---|
| student-1 | 104 | 102 | 104 | student-15 | 100 | 95 | 95 |
| student-2 | 106 | 104 | 103 | student-16 | 102 | 103 | 105 |
| student-3 | 103 | 101 | 104 | student-17 | 105 | 96 | 104 |
| student-4 | 102 | 100 | 96 | student-18 | 105 | 104 | 105 |
| student-5 | 105 | 103 | 103 | student-19 | 97 | 94 | 94 |
| student-6 | 109 | 106 | 105 | student-20 | 105 | 104 | 109 |
| student-7 | 104 | 100 | 98 | student-21 | 105 | 101 | 105 |
| student-8 | 105 | 99 | 102 | student-22 | 107 | 104 | 105 |
| student-9 | 106 | 100 | 103 | student-23 | 101 | 101 | 103 |
| student-10 | 104 | 104 | 104 | student-24 | 107 | 104 | 106 |
| student-11 | 104 | 103 | 102 | student-25 | 105 | 99 | 103 |
| student-12 | 106 | 105 | 103 | student-26 | 108 | 105 | 106 |
| student-13 | 107 | 108 | 105 | student-27 | 107 | 105 | 105 |
| student-14 | 106 | 105 | 105 | | | | |
| **Mean Value** | 104.63 | 102.04 | 103.03 | **Std Dev** | 2.57 | 3.38 | 3.46 |
| **Std Error** | 0.5 | 0.65 | 0.67 | **Variance** | 6.63 | 11.42 | 11.96 |

**Table 1.** Near Acuity score for each subject including overall means and standard errors.

### 3.1 Pupil size

The results of the pupil area measurements for each of the 4 children tested is shown in **Table 2.** A paired t-test comparing the 70 datum for each child and for each of the equi-luminance lighting conditions showed there was a highly significant difference in pupil area for all 4 of the tested children with the high CCT condition providing a smaller pupil. The mean area difference between the 2 conditions averaged over the 4 children was 2.18 mm2.
This magnitude of change in pupil area is larger than would be deduced from previous results of young adults for the lighting conditions of the test room 1. This larger mean difference in pupil area for the children might not be expected because those previous young adults were measured with fixations greater than 1 meter but may be due in part to the claimed absence of accommodative pupillary reflex in young children 7. Examination of the video pupil images of the 4 children showed that they were approximately circular in shape. To this extent, a mean difference in pupil diameter can be obtained from the data of Table 2 with the resultant value of 0.31 mm.

| H-CCT | 11-Y-G | 10-Y-G | 11-Y-G | 10-Y-B |
|---|---|---|---|---|
| **Min** | 15.49 | 11.08 | 11.92 | 11.14 |
| **Max** | 19.41 | 15.92 | 15.40 | 14.10 |
| **Avg** | 17.71 | 13.03 | 13.72 | 12.64 |
| **L-CCT** | **11-Y-G** | **10-Y-G** | **11-Y-G** | **10-Y-B** |
| **Min** | 17.96 | 14.02 | 14.10 | 12.42 |
| **Max** | 23.28 | 16.92 | 16.96 | 14.58 |
| **Avg** | 20.64 | 15.89 | 15.53 | 13.75 |
| **H-CCT/L-CCT** | 11-Y-G | 10-Y-G | 11-Y-G | 10-Y-B |
| **Min** | 0.86 | 0.79 | 0.85 | 0.90 |
| **Max** | 0.83 | 0.94 | 0.91 | 0.97 |
| **Avg** | 0.86 | 0.82 | 0.88 | 0.92 |

**Table 2.** Average, min and max of measured pupil areas for each of the 4 children based on data obtained from 70 digital images per condition.

## 4. 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 2 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 2 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 8 and with previous laboratory spectral acuity studies of both young and elderly adults 1.
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 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 studies1.
Each of the 4 children whose pupil size was measured under the 2 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 4 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 response9 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.

Is acuity relevant for 'real world conditions'?

It has been argued that the small size of letters that are employed to establish the spectral acuity effect are not present in 'real world' conditions and therefore the pupil size and spectral effect is irrelevant to the real environments of interest to lighting practice10. This is not the case because the significance and relationship of acuity for 'real word' conditions has been established over a long period of time by the vision and optometric community.

The most extensive of this long history of work in vision relates acuity (the threshold condition) to reading. One of the earliest works is that of Flom11 who introduced the concept of 'visual acuity reserve'. Flom determined that reading speed slowed as readers approached their threshold print size (letter acuity): i.e., the deceleration in reading speed indicated that the limit of the readers "reserve of resolving power" was approaching. Since the 1980s other vision researchers12 have developed tests and conducted studies to determine the magnitude of the visual acuity reserve for normally sighted people of all ages.

Visual acuity reserve for individual readers is expressed as the ratio between the size of the smallest print that can be read with best efficiency and comfort, to the smallest size print that can be just barely correctly read (acuity condition).

The essence of this body of work is that a persons reading speed will begin to slow down as letter size decreases. The slowdown starts to occur when the letter size reaches about 3 to 4 times the acuity limit and then begins an abrupt reduction in speed as letter size approaches the acuity limit. This size where the slowdown begins is referred to as the 'critical print size' The region of letter sizes larger than this critical size is referred to as the visual comfort zone and people like to be in their comfort zone.

For example, newspaper print is generally 8-point type and at normal reading distance this corresponds to 6/15 vision. A person needs to have just slightly better than 6/6 vision to be assured that they are in the visual comfort zone. Newspapers are not printed with 3-point type although a person with 6/6 vision could read such type and thereby save much paper. The reason is because reading at that size would not be in the comfort zone. The better the acuity a person has the more reserve that person has for remaining in the visual comfort zone with all visual tasks.

In particular Lueck et al13 showed that normally sighted children of the age group studied here, needed four times their resolution reserve in order to reach maximum reading speed.

Thus a lighting spectrum that improves visual acuity will provide a larger comfort zone. Since there is much material in the workplace of 3 to 4 times threshold size, the assurance of 6/6 acuity is not of irrelevance there.

A second and related point concerns posture. As letter size approaches the visual comfort critical size, people will initiate posture adjustments or even squint, i.e. they will lean forward or make other positional/facial changes in the attempt to remain in the visual comfort zone. Such adjustments introduce postural constraints and possibly physical discomfort if occurring over long periods. Therefore the better the acuity the more postural and visual freedom.

In addition to the above considerations there is the beneficial effect of better acuity related to the visual clarity of edges in the visual scene. Most all objects have edges and boundaries and these will be seen more sharply and clearly when acuity is best, as acuity is a measure of the visual system's high spatial frequency resolution.
Another aspect of the spectral effects is directly related to the value of smaller pupils for reducing accommodative response by increasing depth of field14. Through this effect, smaller pupils can contribute to lessening visual fatigue associated with the constrained (fixed) accommodative requirements of computer visual tasks.
These positive visual effects, enhanced by lighting spectral choice provide the circumstances for lighting practice to improve the ergonomics of the workplace environment. To claim that acuity and pupil size control is irrelevant to this environment invites a missed opportunity beneficial to the quality of illumination engineering.

## 4. CONCLUSION

The results presented here show that by changing from the more traditional 3500K lighting to higher colour 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.

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## ACKNOWLEDGEMENTS

We thank Verilux Inc. of Stamford, CN and CEO Nicholas Harmon who kindly purchased the test room fixtures and the related control components that allowed this study to be undertaken. We also thank Michael Barrere electrical contractor San Francisco, CA for donating engineering support including construction of the wall control unit.

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