Effect of light-emitting diode colour temperature on magnifier reading performance of the visually impaired

Background: As light-emitting diodes become more common as the light source for low vision aids, the effect of illumination colour temperature on magnifier reading performance was investigated.

Methods: Reading ability (maximum reading speed, critical print size, threshold near visual acuity) using Radner charts and subjective preference was assessed for 107 participants with visual impairment using three stand magnifiers with light emitting diode illumination colour temperatures of 2,700 K, 4,500 K and 6,000 K. The results were compared with distance visual acuity, prescribed magnification, age and the primary cause of visual impairment.

Results: Reading speed, critical print size and near visual acuity were unaffected by illumination colour temperature (p > 0.05). Reading metrics decreased with worsening acuity and higher levels of prescribed magnification but acuity was unaffected by age. Each colour temperature was preferred and disliked by a similar number of patients and was unrelated to distance visual acuity, prescribed magnification and age (p > 0.05). Patients had better near acuity (p = 0.002), critical print size (p = 0.034) and maximum reading speed (p < 0.001), and the improvement in near from distance acuity was greater (p = 0.004) with their preferred rather than least-liked colour temperature illumination.

Conclusion: A range of colour temperature illuminations should be offered to all visually impaired individuals prescribed with an optical magnifier for near tasks to optimise subjective and objective benefits.

Illumination is critical to optimising visual function, particularly in the ageing eye, and even more so for people with ocular disease. Lighting can improve contrast sensitivity, but can also cause glare. Traditionally, most low vision aids have been illuminated by tungsten bulbs, as they are relatively low cost and bright. When compared with light-emitting diodes (LED), they are relatively inefficient in their use of power, not as bright and have a much shorter life span. Light-emitting diode technology, which is available in many recent magnification devices, overcomes these drawbacks and is available in a range of (correlated) colour temperatures; however, the optimal colour temperature and the optimal method of prescribing this clinically are yet to be determined. Light-emitting diodes are based on semiconductor diodes, which, when switched on, cause electroluminescence. The colour of the light corresponds to the semiconductor’s energy gaps and thus the energy of photons released by the electrons in the device. The resulting blue colour is converted to a white output using a yellow fluorescent phosphor.

It is controversial whether certain colours and lamps can be used to improve reading performance in people with low vision. Reading is the skill of extracting and understanding written
The increase was from 10 per cent of hand magnifiers being discontinued to approximately 80 per cent of the illuminated magnifiers prescribed. In the final sample taken in 2003, the proportion with internal illumination increased from approximately 50 to 80 per cent. In the final sample taken in 2003, LED-illuminated magnifiers were noted for the first time, constituting approximately 80 per cent of the illuminated hand magnifiers and 30 per cent of the illuminated stand magnifiers prescribed.

The aim of the present study was to assess the effect of varying colour temperature of LED-illuminated stand magnifiers on near visual function in the visually impaired.

**METHODS**

Participants were recruited from the outpatients eye department at Queens Medical Centre, University of Nottingham, and enrolled in the study following informed consent after explanation of the nature and possible consequences of the study. The research was approved by the local research ethics committee and adhered to the tenets of the Declaration of Helsinki. Inclusion criteria were ophthalmological confirmation of visual impairment and a visual acuity of 6/9 Snellen or worse in the better eye, ability to read English fluently and the clinical need for a magnifier to perform fine reading tasks (near visual acuity of N8 or worse at the individual’s habitual working distance). A total of 107 participants (61 women and 46 men) were assessed, with an age range of 37 to 96 years (median 82 years). The principal causes of visual impairment were age-related macular degeneration (AMD; 91), diabetic retinopathy (8), retinal detachment (2) and other ocular conditions (6). Visual acuities ranged from 6/9 to 0.5/60 (logMAR equivalent: +0.20 to +2.10 logMAR). Eighty-five of the participants were experienced users of optical magnifiers, with the remainder having been prescribed magnifiers in the low vision clinic assessment that immediately preceded the data gathering session for the present study.

Magnifier heads (A Schweizer Gmbh, Forchheim, Germany) ranged from +8.00 D to +28.00 D in 4.00 D steps with additional powers of +39.00 D, +48.00 D and +56.00 D available. The stand-magnified heads minimise external light (which was constant for all conditions) from illuminating the task and are of white plastic to maximise even illumination. The colour temperatures, trialled in counterbalanced order, were nominally 2,700 K, 4,500 K and 6,000 K. The illumination of the battery-powered handle LED was adjusted so that illuminance in the visible spectrum was within 50 lux of 1800 lux, as measured with a CA 810 Luxmeter (Chauvin Arnoux, Slough, UK). A PR-650 SpectraScan SpectraColorimeter (Photo Research Inc, Chatsworth, CA, USA) was used to generate spectral outputs for each LED imaged directly along their primary axes (Figure 1). Subjects ranked each of the three colour temperature illuminations (best, in between or worst performance) on ease of reading, comfort and overall preference and any resulting comments were recorded.

Each participant’s refractive correction was optimised as part of their low vision assessment and their logMAR visual acuity measured for each eye. The need for optical magnification for fine print reading was confirmed during the low vision assessment and the power of the stand magnifier head used to assess reading speed selected to match the magnification of the device prescribed during the low vision assessment. In combination with the stand magnifier, participants used their preferred spectacle correction, which was distance single vision for nine, near single vision for 21, bifocals for 42, varifocals for eight and unaided for 27 participants. The choice of spectacle lens type will have affected the effective magnifica-

**Figure 1.** Spectral radiance of the 2,700 K, 4,500 K and 6,000 K colour temperature stand magnifier light-emitting diodes
ton of the magnifier but this was consistent between the colour temperatures assessed for each individual.

Reading speed was assessed with the Radner reading charts, which have been shown to provide reliable measures of reading performance. They consist of paragraphs sized from 1.2 to -0.2 logMAR in 0.1 logMAR steps with the same number of words (13), word length, number of syllables, position of words, lexical difficulty and syntactical complexity. All subjects were allowed to use whichever method of viewing (monocular or binocular) and eye-to-magnifier lens distance that was most comfortable for them, while maintaining the magnifier head flat on the reading chart. Each participant’s viewing style was monitored by observation for consistency across the different types of LED. The participants were asked to read each chart sentence aloud, as precisely and quickly as possible, without repeating words or correcting errors. The time taken to read the sentence was recorded and any mistakes, including words that were omitted or misread and the number of syllables in that word, were noted. As outlined in the Radner chart manual, the patient’s reading acuity was calculated as:

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\text{logRAD score} = \log \text{RAD for lowest line read} + (0.005 \times \text{syllables of incorrectly read words}).
\]

The maximum reading speed was an average of all reading speeds before the critical print size (CPS), which was calculated as the visual acuity at which the reading speed reduced by more than two standard deviations below the maximum reading speed. The logMAR to logRAD difference was calculated by subtracting the distance visual acuity of the best eye from the calculated logRAD score.

Maximum reading speed, CPS and logRAD score with each of the colour temperatures was compared with repeated measures analysis of variance. All measures achieved with the magnifiers were correlated to distance visual acuity, magnifier power and age. The difference between experienced compared with non-experienced optical magnifier users and AMD compared with subjects with other causes of visual impairment were compared with a one-way analysis of variance. Chi-squared was used to assess how the clinical performance was related to subjective preference in colour temperature illumination. With 107 subjects and using the repeatability of the Radner chart, the study was 80 per cent powered to detect a 0.6 words per minute (wpm) change in maximum reading speed, a 0.005 change in logRAD score (which also applies to the logMAR to logRAD difference) and a 0.18 logMAR change in CPS.

### RESULTS

The corrected maximum reading speed (F = 0.037, p = 0.964), logRAD score (F = 0.413, p = 0.662), CPS (F = 0.024, p = 0.977) and the logMAR to logRAD difference (F = 0.662, p = 0.517) did not differ with colour temperature (Table 1). There was no difference between new and experienced magnifier users in corrected maximum reading speed (F = 0.046, p = 0.831), logRAD score (F = 0.449, p = 0.773), CPS (F = 1.657, p = 0.196) and logMAR to logRAD difference (F = 0.442, p = 0.644). There was an interaction between the maximum reading speed and illumination colour temperature, with experienced users reading faster with the 6,000 K and slower with the 2,700 K colour temperature illumination than new users (F = 4.884, p = 0.009).

Maximum reading speed, logRAD score and CPS achieved with the magnifiers were correlated to distance visual acuity and prescribed magnification with all three colour temperature illuminations but were unrelated to age other than maximum reading speed, which decreased with increasing age (Table 2). The logMAR to logRAD difference was also correlated with distance visual acuity and prescribed magnification but was only significantly negatively correlated with age when the 4,500 K colour temperature illumination was used.

The visually impaired ranked ease of use, visual comfort and overall performance in the same order for each colour temperature in all cases. The preference for colour temperature was evenly spread with 36 participants preferring 2,700 K, 34 preferring 4,500 K and 36 preferring 6,000 K colour temperature illumination. The 2,700 K colour temperature was rated as the worst by 45 subjects compared with 28 subjects with 4,500 K and 33 subjects with 6,000 K, although this difference was not statistically significant (Chi-squared = 4.321, p = 0.115). Colour temperature illumination preference and dislike were unrelated to distance visual acuity (F = 0.429, p = 0.621; F = 1.176, p = 0.313, respectively), prescribed magnification (F = 0.120, p = 0.887; F = 2.139, p = 0.123) and age (F = 0.094, p = 0.910; F = 0.396, p = 0.674). Patients had better near acuity (0.28 ± 0.53 logRAD versus 0.34 ± 0.61 logRAD, p = 0.002), CPS (0.47 ± 0.45 logMAR versus 0.52 ± 0.53 logMAR, p = 0.034), maximum reading speed (108 ± 100 wpm versus 99 ± 96 wpm, p < 0.001) and logMAR to logRAD difference (-0.31 ± 0.53 logMAR versus -0.26 ± 0.61 logMAR, p = 0.008). Patients who preferred 2,700 Kcolour temperature illumination had a 0.6 logMAR versus 0.53 logMAR, p = 0.046).

### Table 1. Reading metrics with colour temperature of the illuminated stand magnifier (n = 107)

<table>
<thead>
<tr>
<th>Colour Temperature</th>
<th>Maximum Reading Speed (words per minute)</th>
<th>logRAD Score</th>
<th>Critical Print Size (logMAR)</th>
<th>logMAR to logRAD Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,700 K</td>
<td>104 ± 50</td>
<td>0.29 ± 0.30</td>
<td>0.50 ± 0.25</td>
<td>-0.31 ± 0.26</td>
</tr>
<tr>
<td>4,500 K</td>
<td>104 ± 50</td>
<td>0.29 ± 0.28</td>
<td>0.49 ± 0.25</td>
<td>-0.30 ± 0.27</td>
</tr>
<tr>
<td>6,000 K</td>
<td>104 ± 52</td>
<td>0.30 ± 0.30</td>
<td>0.49 ± 0.26</td>
<td>-0.29 ± 0.30</td>
</tr>
</tbody>
</table>
logMAR, p = 0.004) with their preferred rather than their least-liked colour temperature illumination.

Participants with AMD were older than the other subjects with visual impairment (82.0 ± 7.0 years versus 64.4 ± 16.1 years) but there was no difference in reading performance (p > 0.05) or subjective preference (Chi-squared p > 0.20) with any of the colour temperature illuminations.

**DISCUSSION**

Most measures of reading ability did not differ with colour temperature illumination of the magnifier. In general, there was no difference between new and experienced low vision aid users in reading ability or subjective preference to the colour temperature of the illumination, suggesting that it is unlikely that users adapt to the illumination colour temperature of their magnifier. Despite reading size metrics being unaffected by age, the reading speed was greater and both the smallest size read and the CPS were better in the subjects who had better distance visual acuity and lower amounts of prescribed magnification. The distance visual acuity and the prescribed magnification are obviously related (0.577, p < 0.001). This highlights that although enlargement using stand magnifiers can enhance visual acuity, there are significant drawbacks such as a more restricted working distance, optical aberrations from the high-powered lenses and a restricted field of vision, which impact on the achieved reading ability. The logMAR to logRAD difference was significantly associated with the prescribed magnification as expected, as optical enlargement should allow smaller words to be read and hence drop the logRAD score; however, the benefit achieved (on average 0.3 logMAR or three logMAR lines at 1.26 times enlargement per line, hence 2.0 times) was lower than the stated magnification (on average 3.8 ± 1.7 times). This will relate partly to the restrictions of optical magnifiers already described along with the individual’s ocular pathology, which is known to affect distance and near visual acuities to different degrees. There was no difference in reading ability or subjective preference between participants with AMD and those with other causes of visual impairment in the present study. This population, as with the low vision population as a whole, mainly had visual loss due to AMD and hence the results can be confirmed only for this population, although the results seemed to be unaffected by the condition causing low vision. In addition, reading on the near chart involves lowercase letters and word recognition, which results in a poorer visual acuity than that measured at the same distance with an upper case chart. Age-related maculopathy is known to affect colour discrimination but the lack of correlation with visual acuity, which can be taken as an indirect measure of the severity of the age-related maculopathy, suggests that an acquired colour defect is unlikely to affect the LED colour temperature preferences found in the present study. The decrease in reading speed with age agrees with previous studies.

All colour temperature magnifier illuminations were equally liked or disliked, with that preference projected onto all aspects of the magnifiers, namely, ease of use, visual comfort and overall performance. While the strength of preference of one colour temperature illumination over another was not directly quantified, comments from patients indicate that only seven did not perceive much difference between them. The preference could not be predicted from participant age, cause or severity of visual impairment. Some commented on differences in glare and reflections, apparent intensity and contrast, apparent text size and letter doubling or jumbling with the different colour temperatures. Hence, media opacities, to which glare and reflections are generally attributed, might influence subjective preference for the colour temperature of the illumination of the magnifier more than the primary cause of visual impairment. Whatever the cause of these subjective differences, patients did read smaller print and were faster with their preferred rather than least-liked temperature illumination, despite the relatively modest change in spectral radiance of the LED.
from 2,700 K to 6,000 K (Figure 1). Although one must be wary of a placebo effect influencing the results with studies involving subjective rating, patients were given no reason to believe one colour temperature should out-perform another. The difference was an improvement of 19 per cent in near acuity, 10 per cent in CPS, nine per cent in maximum reading speed and 18 per cent in logMAR to logRAD difference, and hence appears to be clinically as well as statistically significant. Thus, magnifiers that offer a range of illumination colour temperatures will benefit a larger number of patients. Therefore, it should be considered best practice that a range of illuminations of different colour temperatures is offered to all visually impaired individuals who are prescribed an optical magnifier for near tasks to optimise their reading ability.

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REFERENCES