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LIGHTING FOR DE-GENRATIVE EYE CONDITIONS

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Introduction

Increasing lighting levels is frequently discussed as an effective means of enhancing the remaining vision of people who are partially sighted. Lighting is however a multi-dimensional phenomenon that relies on the interaction of a number of variables including: illuminance, luminance, colour, contrast, object size, spatial dimensions, surfaces and the human visual system. The research will focus on the quantitative and qualitative aspects of lighting and the lighting types in relation to people with de-generative eye conditions. It is based on a review of the general lighting and vision impairment literature. Whilst there are many similarities between the recommendations for normally and partially sighted individuals, there are also significant differences that require further investigation.

Light and vision

Light is the product of radiation absorbed by the photoreceptors of the human eye. They absorb the wavelengths between 380nm and 760nm of the electromagnetic spectrum. Contrast detection is the basic task from which all other visual behaviours are derived (Kaufman & Haynes, 1981a). Normally, the operation of the visual system involves detection of the stimulus in the peripheral visual field. The eye is then turned to bring the stimulus to the central field (specifically the fovea) for more detailed examination. For a stimulus to be initially detected it needs to be contrasting in luminance or colour and change in space or time. For this operation to successfully take place, (Boyce 2003) discusses five important parameters: the visual size of the stimulus, its luminance and chromatic contrast, the retinal image quality and retinal illumination. Lighting levels underpin the effectiveness of each of these parameters.

(Boyce 2003) identified a “plateau and escarpment” effect associated with increasing levels of illumination and human visual performance. They found that visual performance improves only slightly for people with normal vision as illumination levels increase beyond 10 lux. Visual performance plateaus with increasing illumination until it reaches a point of escarpment where it plummets with further increases in illumination. Thus for the normally sighted population, visual performance changes very little with changes in lighting conditions. In fact, much of the lighting literature warns the lighting designer to not be caught up in the belief that increasing illuminance levels improves the visibility and visual performance of a task (Veitch & Newsham, 1996). Cook (2000) echoes this view. He argues that for people with vision impairment luminance is equally as important as illuminance. Quality, not just quantity, is necessary for what constitutes good lighting. The quantity of illumination has been found to significantly improve the visual performance of people with impaired vision as will be further outlined.

Illuminance, Luminance and Other Relevant Lighting Terms

Illuminance is the photometric term used to describe the amount of light visible to the human eye (known as luminous flux) incident at a point on a surface (Boyce, 1997; Kaufman & Hayes, 1981a). The unit of measurement for illuminance is lumen per meter^2 or lux. An illuminance or lux meter is the tool used to measure illuminance. It contains a single detector with a human eye response filter (Distl, 2000). Illumination is the general term used to describe the process for producing light.

Luminance is the amount of light visible to the human eye that is emitted in a given direction from a surface (Boyce, 2003; Cook, 2000;). That is the reflected light coming from a surface. Luminance depends on: the incident light on the surface (the illuminance), the reflection properties of the surface, and the direction of viewing the surface (Cuttle, 1980). Colloquially, it is commonly referred to as the "brightness" of a surface or object (Veitch & Newsham, 1996). The unit of measurement for luminance is the candela per meter^2. A luminance meter measures luminance.

Whilst, luminance is the amount of light, colour is the type of light in visible wavelengths being emitted from a surface. Colour is determined by the light's spectral composition and the properties of the eye (Rash & McGowin, 1996). It consists of three components: hue, saturation and lightness. A colorimeter can be used to measure these components.

Light and vision impairment

For the purpose of this research, people with partial sight are those members of the population who have impaired vision that cannot be assisted by spectacles but still have some residual vision. The impaired vision can range from the moderate, where individuals can only perceive the presence of light or dark in an environment. The partially sighted population can perceive illumination levels and lighting is often advocated and used as a way of enhancing their remaining vision. Illumination cannot be perceived by people with *no vision*, who must rely on vision substitution techniques to perform tasks – these people are not included when the phrases "partially sighted" or "vision impaired" are used.

People aged over 70 years of age, commonly experience degeneration of eye sight. The cause of reduced eye sight can include: age related macular degeneration that affects the central visual field; glaucoma that initially affects the peripheral visual field; cataract that causes an increase in the opacity of the lens; and diabetic retinopathy that affects patches of the visual field. A proportion of people live with more than one of these eye conditions. People with partial sight experience deficits in distance and near visual acuities, contrast sensitivity, visual fields, dark/light adaptation, depth perception, and colour vision. Increases in blur and night blindness are additional complications. The cause of and degree to which these deficits occur varies according to the type and stage of eye condition. Less extreme visual changes than those with impaired vision include reduced contrast sensitivity and dark/light adaptation. This is primarily due to a reduction in the pupil size and a yellowing and thickening of the lens (Sanford, 1991). Increases in glare sensitivity can also be present in older people with vision impairment.

It becomes evident when comparing these deficits to the parameters described by Boyce earlier, that visual performance is likely to be significantly reduced for older people and people with partial sight. If detecting contrast is the fundamental basis of the successful operation of the visual system, the reduced contrast sensitivity experienced by vision impaired people becomes a significant limitation. This may be the reason for Cornelissen's (Cornelissen, Bootsma & Kooijman, 1995) finding that contrast sensitivity is a better predictor of vision performance in real world situations than visual acuity for people with vision impairment.

Light quantity

Unlike their normally sighted counterparts, it has been found that people with vision impairment require and benefit from more light. Julian (1983) found that increased illumination benefited people with a range of eye conditions, including cataract, age related macular degeneration and glaucoma. It contributed to improved distance visual acuity, contrast sensitivity, near visual acuity and the perceived ease of task performance. Whilst increases in the amount of light proved beneficial for all and were greater than those required by normally sighted individuals, the amount of the increases varied from individual to individual. People with macular defects benefited from the greatest increase in illumination; people with cataracts benefited from smaller increases in illumination; and those with glaucoma required similar levels to normally sighted people. The glaucoma finding is likely to have occurred because the task used by Julian was a near reading task, and glaucoma primarily affects peripheral visual field, leaving central vision in tact. Julian (1983) also found that people with *vision impairment* were less sensitive to glare than was presupposed.

Cornelissen and colleagues (Cornelissen, Kooijman, van Schoot, Bootsma & van der Wildt, 1994) investigated optimal illumination levels for partially sighted individuals by measuring near and distance visual acuities, contrast sensitivity and object perception in a realistic environment. They found that substantial improvements were made in all aspects of visual performance tested. There was no relationship found between eye condition type and optimal illumination level, highlighting the very individual nature of vision impairment – an observation supported by other researchers in the field (Boyce & Sanford, 2000; Frasse, 1999; Julian, 1984).

The same researchers investigated this phenomenon further by examining the relationship between illumination level and ability to detect and recognise objects in a real world environment (Cornelissen et al, 1995). Again, they found that the light levels at which improvements occurred were often well above the level required by normally sighted subjects. A small proportion of the vision impaired people did demonstrate reduced performance at the higher illumination levels and it was found that illumination levels did vary across individuals. It can be argued that in general, improvements in visual performance could be achieved using moderate to high illumination levels for the majority of people with vision impairment.

In two separate research studies, Kuyk and colleagues examined the mobility performance of adults with vision impairment in standardised indoor and outdoor environments (Kuyk, Elliott & Fuhr, 1998). They compared mobility performance under photopic and mesopic luminance conditions. Performance was measured according to the number of object contacts en route and time taken to complete the route. As expected, people with vision impairment performed worse under the mesopic conditions, again demonstrating the importance of luminance and illuminance levels as well as object contrast. In these studies, visual field deficits and poor scanning abilities were the two most important predictors of poor mobility performance.

Boyce and Sanford (2000) deducted that eye conditions that reduce the amount of retinal illumination with a reduction in the clarity of the retinal image are likely to benefit from increases in illumination. Boyce (2003) outlined the advantages and disadvantages different lighting systems can have for people with different types of vision impairment. For people with cataract, the clouding of the lens limits light absorption but also causes greater light scattering within the eye and retina – causing disability glare. Increasing illuminance levels can overcome the limitations in light absorption but if scattering is high, luminance contrasts are reduced leading to reduced visual capabilities. People with cataracts tend to be very glare sensitive to luminances from luminaires and windows. People with defects in the macula are likely to benefit most from increases in illuminance levels as it improves the amount of retinal illuminace and the clarity of the retinal image. For people with glaucoma and other conditions that cause peripheral field deficits, night lighting is particularly important and beneficial.

LIGHT QUALITY

Whilst a great deal of research has taken place regarding the quantities and amounts of illuminance levels required for visual task performance for both the partially and normally sighted population, the qualitative aspects of lighting deserve (and are increasingly receiving) greater attention by lighting researchers (Vietch & Newsham, 1996). Discussions about quality lighting characteristics typically revolve around the following areas: visual comfort; luminance ratios and uniformity; glare, veiling reflections and contrast renditions; and the colour of the light and its rendition of colours (Kaufman & Hayes, 1981b; Veitch & Newsham, 1996).

A trend is emerging in the vision impairment literature, as well as the lighting design literature, not to only consider illuminance levels (*quantitative*). Authors in the field frequently highlight the following *qualitative* aspects of lighting as being important to the enhancement of visual function for people with partial sight: uniformity, glare control and luminance levels (Boyce & Sanford, 2000; Slay, 2002).

Visual comfort

Visual comfort includes human aspects beyond the visual system's ability to perform a task (Boyce, 2003). It involves: perceived ease of task performance; adequate stimulation of the visual system (not over- or under-stimulation); and limiting potential distractions and perceptual confusion. Causes of visual discomfort by lighting conditions include: flicker, glare; shadows and veiling reflections – most of which relate to the additional *qualitative* aspects of lighting. Visual comfort very much relates to dimensions beyond visual performance alone. Boyce (1997) found that as illuminance levels were raised above 2000 lux a greater proportion of people reported visual discomfort even though increases in visual performance continued to be observed. Cornelissen et al (1994) also found that for people with *vision impairment*, the light levels they preferred were not always optimal for visual performance. Visual comfort is not commonly discussed in the vision impairment literature. In one research study Julian (1983) used perceived ease of task performance as a variable in investigating illumination levels for people with *partial sight* and found that it correlated with increased illumination.

Luminance Ratios and Uniformity

It is a commonly held view in the lighting field that luminance levels of various surfaces in the visual field should be controlled and limited (Kaufman & Haynes, 1981b). The rationale behind this view is to reduce discomfort and eye fatigue resulting from the need for the pupil and lens to adapt to the varying luminance levels within the environment. A quality luminous environment is generally believed to be one that is uniformily lit and has little variation in luminance levels (Hooper, 1984). This is described in the South African Standards for Interior Lighting (SABS0114-1* Edition 2.1 1998), which also specifies recommended luminance ratios for different surfaces and environments. Uniformity is certainly advocated in the vision impairment literature to ease the need for continuous light/dark adaptation, enhance contrast and reduce the effects of glare at the same time (Boyce & Sanford, 2000). Kellogg Smith and Bertolone (1986) also recommend lighting design for older people, should brighten an entire space evenly, as it deals best with the balance between glare sensitivity, contrast sensitivity and the need for more light.

Veitch and Newsham (1996), however suggest that high uniformity across luminance levels may not be as important as traditionally believed and state that further research is required. Hill, Wright and Cook (1998) examined the visual performance of partially sighted subjects in an office environment with varying luminance level conditions. Uniformity and bright ceilings and walls were found to be optimal – a result they found to be similar to research conducted with normally sighted people.

Glare, Veiling Reflections and Contrast Renditions

There are two types of glare commonly discussed in both the lighting and the vision impairment literature: disability and discomfort glare. Disability glare is caused by stray light within the eyes that veils the retinal image of the object to be seen. It results in reduced contrast and can be caused by light sources or bright surfaces. Veiling reflections (otherwise known as reflected glare) are an example of disability glare because they reduce overall visibility of an object. They are caused by light sources being reflected from a surface directly into the central visual field. It causes a reduction in the luminance contrast of the task. Examples of causes include glossy magazines, metal surfaces and reflective materials. It can be controlled by using matte surfaces, adjusting the viewing angle and positioning of the lighting system behind or to the side of the individual and the task (Kaufman & Haynes, 1981b).

Discomfort glare refers to the discomfort experienced when viewing unexpected bright sources of direct or reflected light. It is a physiological occurrence where the eye is forced to adapt to the new darker or lighter luminance level (Dickinson, 1998).

Glare is a factor frequently discussed in the vision impairment literature. As mentioned earlier, glare sensitivity increases with the aging lens as it yellows and thickens (Sanford, 1999). It is a particular concern with certain eye conditions such as cataract where light scattering within the eye is increased and causes disability glare. Thus, the increases in illuminance levels espoused in the literature are frequently coupled with statements to reduce the potential for glare. Nonetheless, Julian (1983) found that vision impaired individuals were less glare sensitive than commonly believed. Further research is required in this area to improve understanding of the relationship between glare and various eye conditions.

Colour

Colour refers to the spectral composition of light. In relation to lighting there are two important attributes: the colour appearance of the light source and the colour rendering properties of the light source. The colour appearance of the light source influences the overall colour impression of an area (Philips Lighting, 2008). It is indicated by the colour temperature, measured in Kelvin (K), and ranges from a “warm” 2500K incandescent lamp to a ‘’cool’’ 5000K – 7000K light of a cloudy day. The colour rendering properties of a light source relate to how realistic or natural the colours of the objects being lit by the light source appear. They are indicated by a Colour Rendering Index (CRI), symbol Ra, which is a standardised scale with 100 as the maximum value indicating the best colour rendering properties of a light source. A CRI greater than 80 Ra is considered essential where good rendition of colours is desirable (Philips Lighting, 2008).

It is generally believed that natural light is best for performance (Veitch & Newsham, 1996). Broad spectrum lighting, that is, with high CRI values, is most similar to natural daylight. Little discussion concerning broad spectrum lighting can be found in the vision impairment literature. Along with reduced luminance contrast sensitivity, people with vision impairment also experience reduced chromatic sensitivity, lightness sensitivity and have greater difficulties distinguishing between hues that are situated close together on the colour spectrum (Arditi & Knoblauch, 1996). Different light sources have different spectral emissions (Boyce, 2003). As a result, colours appear different which is why a high CRI value is required. Boyce (2003) goes on to state that the effect of the light spectrum is more important than illumination for colour discrimination. Mention is rarely given to the colour properties of light sources that meet the needs of people with impaired vision and it has not been empirically tested to date. Boyce and Sanford (2000) recommend light sources with high CRI values are necessary. Frasse (1999) specifies people with vision impairment require a CRI value greater than 90 Ra.

LIGHTING TYPES

Light is produced by natural (daylight) and artificial light sources. The use of each of these sources are commonly discussed in a general way in the vision impairment literature. Lighting designers are encouraged to find a balance between the use of natural and artificial light to minimise energy consumption costs and to facilitate visual performance (and productivity in work environments) and to create an aesthetically pleasing environment (Kellogg Smith & Bertolene, 1986).

Natural light

Natural light is considered to be the best type of light and most people prefer it, including those with vision impairment (Cook, 2000). However, natural light is the most difficult to manage because it is so variable and is a cause of heat and glare (Kellogg Smith & Bertolone, 1986). Its magnitude, spectral content and distribution all vary according to the weather conditions, time of day and the season (Boyce, 1997). The vision impairment literature frequently discusses the need to control daylight to maximise illumination and manage it as a glare source (Turner, 1991). The use of window tinting, awnings, blinds and curtains is recommended (Cocke, 1992) – particularly in relation to the control of direct beam sunlight.

Artificial Light

In relation to vision impairment, the two most commonly discussed artificial light sources are incandescent and fluorescent light sources. Whilst the lighting industry produces other types of light sources,these will not be discussed.

1. **Incandescent light sources**
   Incandescent light sources are the most popular sources used in domestic lighting environments. They are cheap to install and easy to replace. Being high wattage, they have the most expensive running costs. Halogen light sources are a type of incandescent light that are increasing in popularity because of the brighter light they produce at lower wattage. The light beam produced by incandescent light sources is long and narrow and they have extremely good colour rendering properties. Kellogg Smith and Bertolone (1986), as well as vision impairment commentators recommend that incandescent light is best used for spot and task lighting. Lighting designers also use it when they wish to create a non-uniformly lit environment (Kellogg Smith & Bertolene, 1986).

   Merz (1982) states that a high wattage single light source in the middle of a room, is not adequate to light a room in a home. However, his research found that this is how the majority of homes are lit, resulting in illuminance levels that are well below those recommended by the lighting Standards. Julian (1983) also found this in the homes of people with vision impairment. Incandescent lighting is generally inadequate for providing ambient lighting to meet the needs of people with vision impairment, unless there is more than one light source in the area and they are positioned carefully – to eliminate any shadows (Dickinson 1998).

2. **Fluorescent light sources**
   Fluorescent light sources are less frequently found in domestic settings. They are the most commonly used light source in office environments as well as in other institutional settings such as schools and hospitals. The beam they produce is wide and diffuse resulting in soft-

edged shadows. They are much more energy efficient than incandescent light sources. They come in a range of colour appearances and colour rendering properties. Fluorescent lighting works best where a great amount of general light is required in a space with ceiling heights less than 4.2 metres high (Kellogg Smith & Bertolene, 1986). For people with vision impairment, fluorescent lighting should be used where possible for general lighting purposes because they are most effective in offering a uniformly distributed light (Dickinson, 1998). High CRI values are recommended (Frasse, 1999). Modern triphosphorous fluorescent lighting provides excellent colour rendition and is most effective for ambient lighting for people with vision impairment (Rosenberg, 1996).

CONCLUSION

In general, the body of vision impairment research and literature tends to mirror the findings in lighting research based on normally sighted populations, with one exception: the quantity of illumination required to enhance visual performance. Illuminance levels specified in standards need to be seen as the bare minimum for people with vision impairment as a number of research findings have demonstrated the gains they obtain from increases in illumination that greatly surpass the stipulated South African Standard recommendations. Further research is still required that tests illumination levels with different tasks, beyond reading and mobility. Further research is also required to investigate the optimum qualitative aspects of lighting required by vision impaired people. In particular, the relationship between various eye conditions and glare, and optimal lighting systems that incorporate visual comfort, colour rendition, spectral distribution, uniformity and lighting type.

REFERENCES

- Arditi, A. & Knoblauch, K. 1996. Effective colour contrast and low vision. In B. P. Rosenthal & R. G. Cole (Eds.), *Functional assessment of low vision.* St Louis: Mosby: 129 – 135.
- Boyce, P.R. 1997. Illumination. In G. Salvendy (ed.). *Handbook of human factors and ergonomics.* New York: John Wiley and Sons: 858 – 890.
- Boyce, P. R. & Sanford, L.J. 2000. Lighting to enhance visual capabilities. In *The Lighthouse handbook on vision impairment and vision rehabilitation*, vol. 1. New York: Oxford University Press: 617 – 636.
- Boyce, P. R. 2003. *Human Factors in Lighting*. London: Taylor & Francis.
- Cocke, E. A. 1992. Housing modifications for persons who are blind or visually impaired. Review, 1, 23-28.
- Cook, G. 2000. Light and lighting: Quality in design. Access by Design, (84):21-23.
- Cornelissen, F. W., Kooijman, A. C., van Schoot, E. A. J., Bootsma, A. & van der Wildt, G. 1994. Optimising illumination for visually impaired persons: Comparing subjective and objective criteria. In A. C. Kooijman, P. L. Looijestijn, J. A. Welling and G. J. Van der Wildt (eds.) *Low vision: Research and new developments in rehabilitation.* Amsterdam: IOS Press: 68 – 77.
- Cuttle, C. 1980. *Lighting for good visual conditions in workplaces*. Wellington, New Zealand: Accident Compensation Commision.
- Dickinson, C. 1998. *Low vision: Principles and practice.* Oxford: Butterworth Heinemann.
- Distl, R. 2000. Measure what you see. *Photonics Spectra*: 176 – 180, May.
- Frasse, K. 1999. Bringing things to light: An exploration of lighting characteristics and strategies. Access Review, 1 (2): 4 – 8.
- Hooper, E. G. 1994. Lighting. In J. Ridely (ed.). Safely at work, 4th ed. Oxford: Butterworth Heinemann: 477 – 485.

- Julian, W. G. 1984. The design of buildings for the aged and partially sighted. Lighting in Australia: 17 – 22, December.
- Kaufman, J.E. & Haynes, H. (eds.). 1981b. *IES lighting handbook. Reference volume.* New York: Illuminating engineering society of North America.
- Kellogg Smith, F. & Bertolene, F. J. 1986. *Bringing interiors to light: The principles of lighting design.* New York: Whitney Library of Design.
- Kuyk, T. Elliott, J. L. & Fuhr, P. S. W. 1998. Visual correlates of mobility in real world settings in older adults with low vision. *Optometry and Vision Science*, 75(7):538-547.
- Merz, B 1982. Lighting in homes: A study of quantity and quality. Lighting in Australia, 2(4):26-28.
- Philips Lighting. 2008. Philips Lighting: *Shop lighting application guide.*
- Rash, C. E. & McGowin III, E. 1996. Measuring light. *Information Display*, 8:26-31.
- Rosenberg, R. 1996. Illuminating solutions. *Vision Enhancement*, 1(2): 8-9.
- SABS0114-1* Edition 2.1: 1998.
- Sanford, L. 1999. The importance of lighting for the elderly. *Aging and Vision News,* 11(1):2
- Turner, P. J. 1991. Lighting for low vision – Principles and practice in the design for the elderly. 11(1):14 – 22.
- Veitch, J. A. & Newsham, G. R. 1996, Aug 12. Determinants of lighting quality II: Research and recommendations. Paper presented at the 104th Annual Convention of the American Psychological Association, Toronto, Canada.